

**THE IMPORTANCE OF WATER LEVELS
IN THE MANAGEMENT OF THE
KLEIN RIVER ESTUARY,
HERMANUS**

by

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Submitted to the University of Cape Town in partial
fulfilment of the requirements for the degree of Master of
Science in Environmental Studies.

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MARCH 1986

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ACKNOWLEDGEMENTS

I would like to thank P D Morant and Professor J R Grindley for their supervision and criticism of the text.

I am very grateful to the Agricultural Extension Officer Caledon, Mr van Rooyen, the Nature Conservation Officer Onrus, Mr Visagie and the local people whose opinions contributed towards this thesis.

The Department of Water Affairs were helpful in providing me with data which was used to calculate river flow and estuarine water levels.

I would also like to thank my husband, Howard, who accompanied me on several cold and wet field trips and whose suggestions and criticisms have been invaluable.

I am particularly grateful to Mrs H King who typed and corrected my thesis.

ABSTRACT

The Klein River Estuary is situated at Hermanus in the Western Cape, South Africa. The estuary mouth is normally closed by a sand berm during the summer and open to the sea during the wetter winter months. The estuary forms a shallow lagoon which is becoming increasingly popular for recreational activities. Several management problems have arisen which are now becoming important with the increase in recreational pressure. The main problems are : uncertainty about appropriateness of water levels, marine sand influx and accumulation, flooding of low lying developments, flooding of agricultural lands, decrease in fish catches and indecision about the ideal position of the estuary mouth in the sand berm. This study concentrates mainly on the effects of different possible water levels.

The conclusion is that the estuary water level should be permitted to rise at least as high as the highest level investigated. The estuary should be allowed to breach the sand berm. Developments on low lying land, prone to flooding, should be prohibited and only those structures which would not be damaged by flooding should be allowed in such areas.

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CHAPTER 1

1 INTRODUCTION

1.1 Aims and Objectives

The aim of this study is to provide a comprehensive report upon the relative merits of different water levels in the Klein River Estuary, Hermanus.

The objective of this study is to provide a document to which decision makers can refer during the formulation of a management policy for the estuary.

1.2 Hypothesis and Management Philosophy

It seems reasonable to assume that the most appropriate philosophy to be adopted for the management of a natural environment is one that most closely approximates the condition in which there is no human interference. Therefore, for the the purpose of this study, an *a priori* decision was made to accept this minimum interference approach. Thus all other management options were compared with that which accepts that the estuary must be allowed to function naturally.

Since the Klein River Estuary is only open to the sea for part of the year, such a management philosophy implies that the water level should be allowed to rise to such a level that the sand berm at the mouth is breached naturally.

Management policies for water bodies are becoming more important since the trend towards higher incomes, more leisure time and greater family mobility has led to greater recreational pressure on accessible water bodies (Sowman, 1984). Water bodies such as estuaries are focal points for recreational activities, particularly in South Africa which is not only semi-arid but also has a dangerous high-energy coastline with little shelter. Consequently the pressure on these estuarine areas is continuously increasing not only

in terms of the numbers of visitors but also in terms of duration.

There are three approaches to the management of the coastal zone (which includes estuaries and coastal lagoons) : (i) uncontrolled private development; (ii) limited development - both private and state controlled and (iii) complete state control.

Uncontrolled private development has occurred in the United States of America where development on the coast has been rapid and extensive. A good example of this is the west coast of Florida where building has occurred haphazardly and without control (MacLeish, 1980). This type of development has resulted in a loss of 40% of the United States' coastal wetlands and massive development on "sensitive" coastal areas. The only limits to this type of "management philosophy" are the lack of funds or technology to develop difficult environments, such as mobile dunes or marshes.

A philosophy of limited development in coastal zone areas is one which has been adopted for several areas in South Africa, for example, Natures Valley and Cape Infanta, mainly because a certain amount of development has already occurred in the area. In this case, the developments are privately owned and are often acceptable since they have existed for a reasonably long time and thus have "matured". Generally, the communities are still fairly small. The State could intervene to prevent further development, or to ensure that any further development is in sympathy with the environment. This is a philosophy often adopted by the National Parks Board in which any further development is in the form of campsites and holiday chalets. These are established in an area for the use of the general public. This approach provides access to an area for a large cross-section of the public, it promotes tourism and could be implemented in the form of a public education exercise, by distributing leaflets and having poster displays.

The type of development mentioned above could also be encompassed by the concept of total state control of the

coastal zone in which there are fairly strict environmental controls. The number of people utilizing an area can be controlled by the amount of accommodation available or by the issue of permits for entry. This philosophy would only be really successful in areas which have not been developed and thus do not contain any local residents.

The first option discussed, uncontrolled private development, is now inadvisable and does not usually occur. In the United States, management principles take into consideration the long term cumulative impacts of new developments and the restoration of previously damaged areas (Clark and McCreary, 1980). The holistic approach to the management of resources is also becoming more important in the United States, thus managing the land and water together, especially in the case of an estuary.

The modern principles of coastal zone management in South Africa include the following:

- Avoidance of development of undisturbed areas if nearby proclaimed residential areas are not fully developed.
- Avoidance of private development on dune areas vulnerable to destabilization.
- Avoidance of development in prime ecological areas that may stimulate development in other such areas because of this precedent.
- The discouragement of the reservation of coastal sites for exclusive holiday development (Whitfield et al. 1983).

In the case of the Klein River Estuary, there is extensive private development in Hermanus, but little on the shores of the estuary. This is probably due to the fact that the land has been in the hands of a few enlightened owners.

The main issues concerning this estuary are the increasing recreational pressure and the problems caused by high water levels. Since the main recreational activities of holiday makers are water-related, the estuary requires to be managed in such a way as to ensure there is no environmental degradation. The Cape Department of Nature and Environmental Conservation (CDNEC) have taken over the

management of this estuary in terms of the Cape Nature & Environmental Conservation Ordinance 19 of 1974. Koop (1982) states that the management strategy of CDNEC for estuaries includes the following :

- the conservation of the estuarine habitat and its flora and fauna;
- the control of recreation;
- the management of those species exploited by man in such a way that the ecology of the estuary is not harmed. These species are mainly bait organisms such as the mud prawn *Upogebia africana*, sand prawn *Callinassa kraussii* and the bloodworm *Arenicola loveni*.

All these points are important in the management of the Klein River Estuary.

1.3 Location and Accessibility

The Klein River Estuary lies to the east of the town of Hermanus on the south coast of South Africa, at 34°24'S, 19°18'E (Fig. 1). The estuary is situated to the south of the Kleinriviersberg mountains which form the major part of the catchment area for the Klein River.

This estuarine system is usually open during the winter months when the rainfall is highest. It remains closed for the rest of the year, forming a lagoon or 'vlei'. Between August 1979 and February 1985, the estuary was open for 32 months out of 67. The lagoon is orientated east-west and is approximately 9km long and 2km wide at its widest part.

The lagoon lies between Hermanus and Stanford, with the tar road between these two towns running along its northern bank. Access to the estuary may be obtained on the northern bank at the "Die Mond" campsite, Kettle Point, and the Yacht Club as well as from private farms along this shore. Access from the southern shore is more limited, a dirt track runs from Stanford to "Le Bos" forestry station with access to the lagoon at Wortelgat (Fig. 2) This southern bank of the

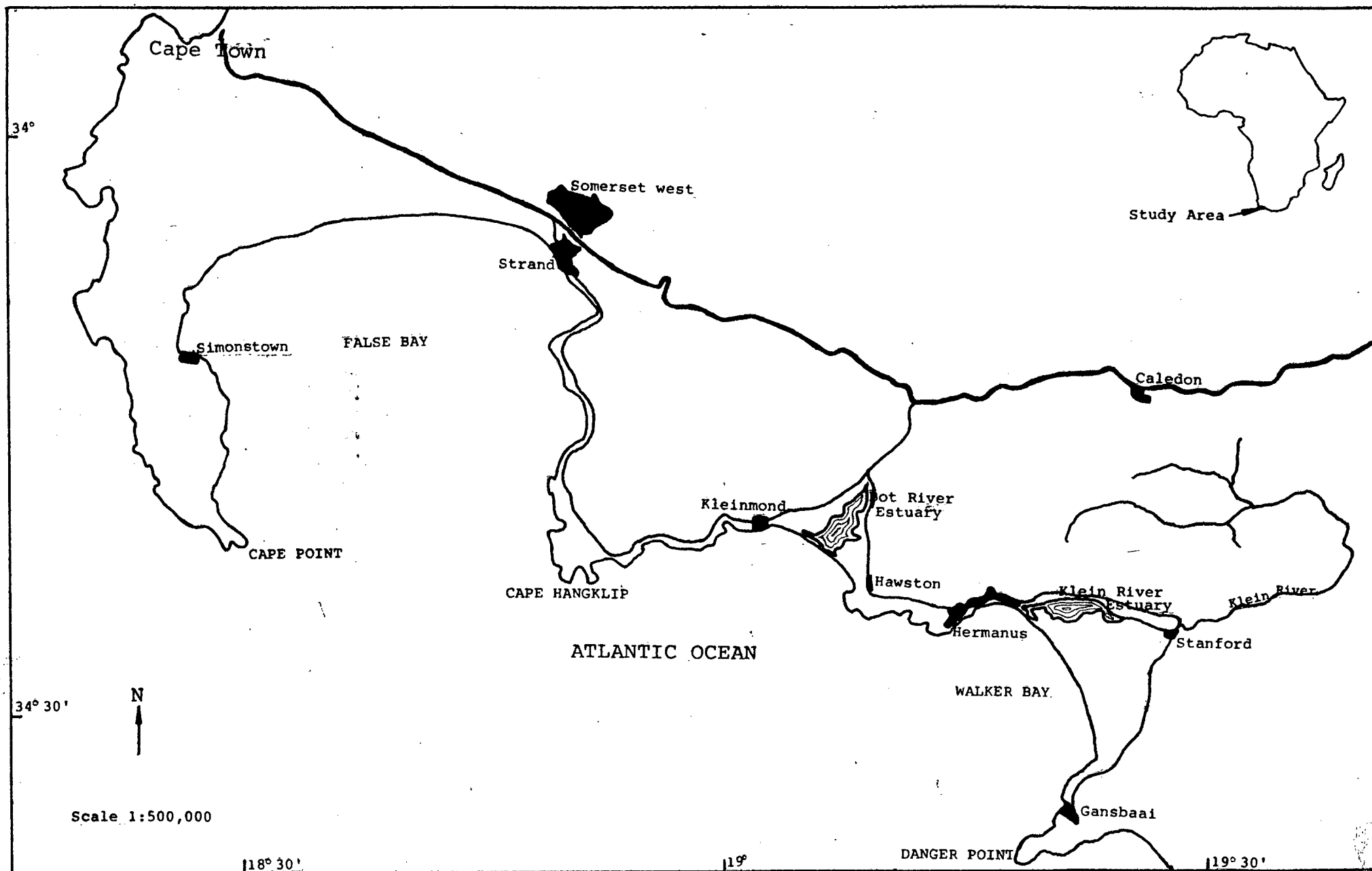
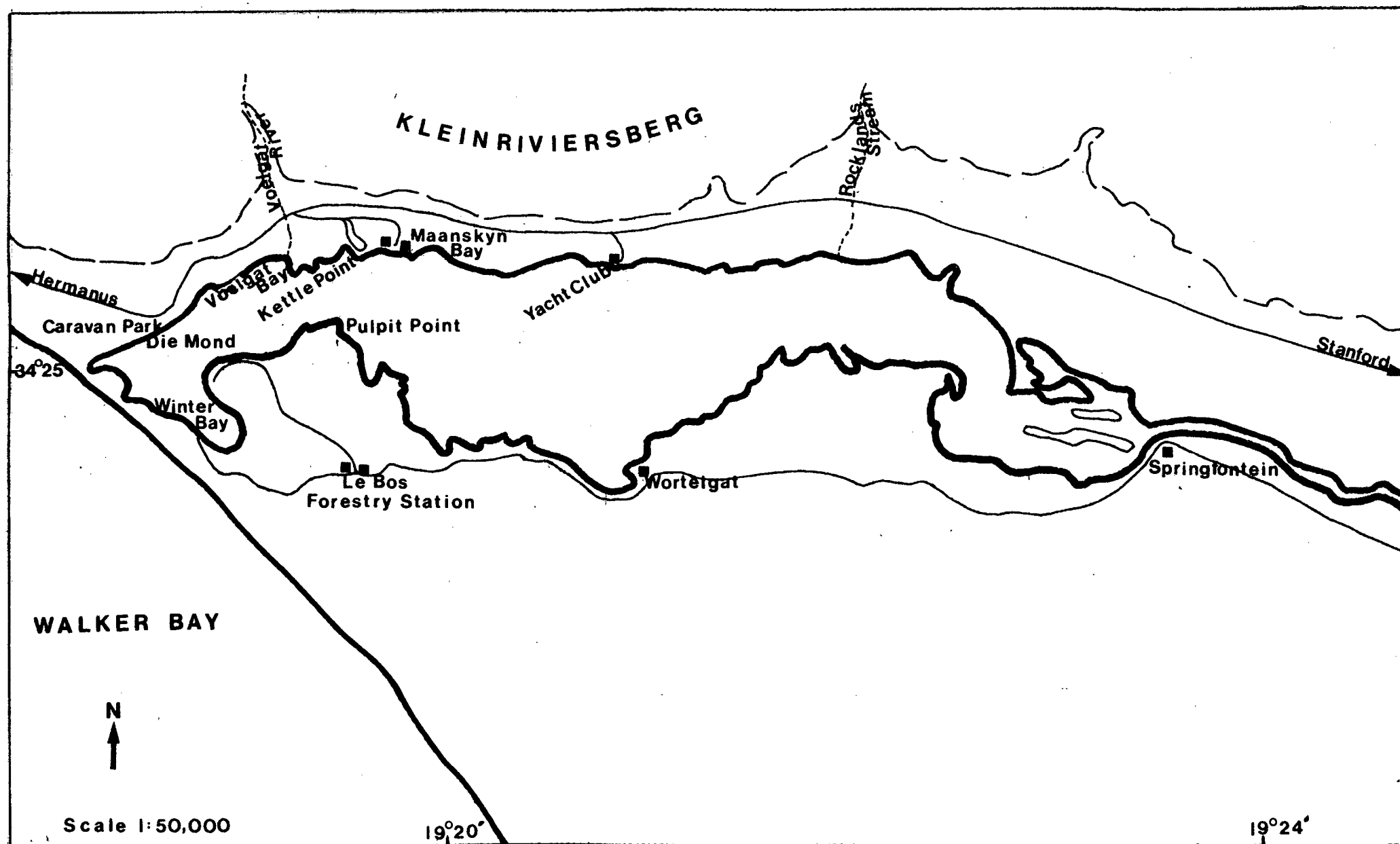


Fig. 1 Location of the Klein River Estuary.

lagoon is thickly vegetated and slopes gently towards the lagoon where it tends to be marshy in areas.

Although this system formally is an estuary, the water body is generally known either as Hermanus lagoon or Kleinriviersvlei, and conforms to Day's (1981) description of an estuary.

Fig. 2 Localities on the Klein River Estuary.



CHAPTER 2

2. WATER LEVEL MANAGEMENT IN ESTUARIES

2.1 Review of some South African estuaries

Many South African estuaries are closed for part of the year by a sand berm across the estuary mouth (Heydorn & Tinley, 1980). The semi-closed nature of South African estuaries renders definition rather difficult and this problem is discussed in Chapter 4. It is a natural process for such estuaries to experience a periodic rise in water level (as a result of increased river flow, heavy rainfall, high runoff and low evaporation). This results in a breach of the sand berm at the mouth of the estuary. In some estuaries this may occur once every five years, but in others, it may be an annual event.

In many of these areas, despite the inherent risk, man has built on or cultivated land around estuaries and rivers. Periodically this land would be flooded naturally as estuary water levels rose. To prevent buildings, land and roads from being flooded, the simplest solution is to artificially breach the sand berm, so that the water level is lowered. These artificial openings are often undertaken prematurely with no thought given to the short and long-term ecological and sedimentological processes and may lead to problems in the estuary such as the influx of marine sediments. High water levels and the flooding of land adjacent to estuaries are common problems encountered in estuarine management, but no two estuaries are the same, thus each estuary needs a specific set of solutions. In order to illustrate the different aspects of water level management in estuaries, water level problems and their solutions in four estuaries are discussed below.

The Hartenbos Estuary on the Cape south coast in Mossel Bay is a popular estuary along the shores of which there is fairly extensive development. However, there is often flooding of the surrounding land due to high water levels.

This estuary has a sand berm across the mouth which has been breached artificially to prevent flooding (Bickerton 1982). One of the main reasons for artificial breaching is that an access road to a holiday cottage is one of the first features to be flooded. Another reason for breaching is to provide clean recreational water during the summer. The rainfall on the Cape south coast is erratic and this estuary can remain closed for long periods, during which it can become eutrophic and foul.

If a flood occurs after a period of drought in which the mouth is closed, the resultant back-up floods the properties which were built below a safe level for example, the 50 yr flood line. The problem is now reduced since the Hartebeeskuil Dam, up stream from the estuary, stops all but the most extreme floods. The water level in the Hartenbos Estuary can be artificially raised so as to cause the estuary berm to be breached. The management philosophy is to artificially re-establish a more natural regime that was destroyed by the dam. This is achieved by using the dam water (which is brackish and cannot be used for irrigation) to simulate natural river flow or to release water to cater for the needs of the estuary, in other words, the river flow into the estuary is controlled.

The Heuningnes Estuary on the south coast between Arniston and Cape Agulhas may, if it remains closed, flood farm land when the water levels rise (Bickerton, 1984). There are extensive driftsands at the mouth of the estuary, thought to have been mobilized by cultivation and overgrazing. These sands tend to block the mouth and potentially, some 24 000 ha of farmland could be flooded. The area is very flat and marshy, and the estuary is usually only open to the sea when Zoetendalsvlei is full.

The Directorate of Forestry has attempted to stabilise the drift sand at the mouth by vegetating the dunes and thus cutting off the source of sediment and helping to keep the mouth of the estuary open. The Directorate of Forestry accepts that the mouth is dynamic and that the artificial dunes on either side may be eroded and require constant

maintenance. However, these artificial dunes keep the mouth narrow thereby raising flow velocities and hence the mouth is kept open by tidal scour.

The fact that large tracts of farmland can be flooded has necessitated the management of this estuary. The estuary is kept open permanently, thus preventing the flooding of valuable wheatlands. This may have caused an increase in salinity of the groundwater around the estuary and an accumulation of sediments in the estuary mouth. This illustrates that there are often 'costs' involved in any management approach.

Sandvlei, on the north-western shore of False Bay, experiences problems concerned with the management of water levels. The estuary has been continually modified by dredging and alterations of the water level since the 1880s (Morant and Grindley, 1982). The banks are artificially stabilised and the waters are extensively used for recreation. The areas surrounding Sandvlei are heavily urbanised and there is a large waterside housing development, Marina da Gama, on the eastern shore of the estuary.

At Sandvlei the aim is to control the water level within fairly narrow limits. Too low a level has an adverse effect on recreation and water circulation within Marina da Gama. Conversely, if water levels are too high the heavily urbanised areas around the vlei are in danger of being flooded. In order to control the water levels, there is a rubble weir across the channel approximately 200 m from the mouth. The rubble weir is used to control the water level within Sandvlei. The mouth has been canalised in order to keep it in one position since it is not feasible to have a dynamic oscillating estuary mouth in such a built up area. The estuary mouth is artificially breached in the winter to release the first floods and it is kept open until the water level begins to fall in early summer. The mouth is then closed by a bulldozer to prevent too great a drop in water level. Sand enters the estuary mouth during the summer when there is insufficient (or no) flow to scour it out. This

sand berm builds up to a much higher level than the weir and thus has to be breached in order to release winter floods and to avoid back-up and flooding of Westlake and Marina da Gama. If the level becomes too low in the summer, water is pumped into Sandvlei to maintain a constant level. It can be seen that the management policy of this estuary is centered on the maintenance of a fairly constant water level.

The Bot River Estuary approximately 20 km west of the Klein River Estuary, is another system that is closed by a sand berm. The Bot Estuary appears to be evolving into a coastal fresh water lake (Koop, 1982). It seems that man is attempting to retard its natural evolution by breaching to maintain (artificial) estuarine conditions. During the winter - the time of highest water levels - properties on the estuary banks are flooded and there is often bank erosion caused by high water levels (Koop, 1982). The Bot River Estuary tends to overflow into the neighbouring Kleinmond Estuary when levels are high, but the consequence of this, is that the Bot rarely opens to the sea (Fromme, 1986). If the Bot River Estuary remains isolated from the sea, the salinity will gradually decrease, leading to an alteration in the fauna and flora as the conditions gradually change from saline to fresh (Branch et al. 1985).

When the estuary is breached, the water level falls so rapidly that the short term effects on the flora and fauna are traumatic resulting in massive reductions in aquatic weeds and invertebrates. This area is also important as a wetland and large numbers of birds are often present e.g. 50 000 coot (Koop et al. 1982). An artificial opening of the mouth can result in a twenty fold reduction in the biomass of birds using the estuary (Branch et al. 1985).

Six plans for the management of this estuary have been proposed, only two of which are viable. Either the estuary should never be breached, or it should be breached on a controlled basis. The latter alternative has been chosen as the most viable proposition in the management of this estuary (Dr. Bally, Department of Zoology, U C T pers.

interference, the system would already have become a coastal lake (Branch et al 1985), this is, therefore, its most natural state. Although the long-term trend is towards the Bot becoming a coastal lake, short-term reversals can take place such as the natural breaching in August 1986 - the first this century. Nothing in nature is absolute and even the best management policies cannot be expected to handle extreme events.

From these four examples, one can see that there are many different solutions to the problem of high water levels in estuaries, from the control of water in the river to artificial opening. Some estuaries in Natal have become so badly silted that they are now above sea level, eg the Mvoti and Mgeni Estuaries (Begg, 1984) where the lagoon ceases to exist since it is filled with sediment. According to Allanson (1983), the Zululand lagoons have decreased in area by 60% in the past 6 000 years. This indicates that estuaries and lagoons are geomorphologically ephemeral features. Even if these features of our coastline are ephemeral, it would be a serious loss if the useful life of an estuary was shortened due to poor management and abuse by man. It is important to devise management plans for these sensitive areas of the coast.

2.2 Review of Klein River Estuary

The village of Hermanus was first proclaimed Crown Land in 1875 (Tredgold 1980) and by 1891 the first hotel had been built. The town was renowned for excellent fishing and has always been a popular place for holiday makers. The Klein River Estuary is ideal for water sports and has been a popular place for sailing since the Hermanus Yacht Club was established in 1910 (Tredgold, 1980). The town has expanded dramatically in the last 20 years, most of the new buildings being holiday houses built between the business centre of Hermanus and the lagoon. These houses are only occupied for part of the year. The resident population of Hermanus is 6 200 and this number increases to approximately 20 000 during holiday periods. During weekends the population increases by approximately 1 000 (Mr C Sim, Town Clerk,

Hermanus, pers. comm.). In addition to this increase, the campsite at Die Mond (Fig. 2) has 270 sites but is only full between mid-December and mid-January. The recreational pressure on the lagoon is high during these periods as it is utilized for fishing, sailing, boardsailing, water skiing and swimming.

Fishing has always been a major sport in Hermanus, the Klein River Estuary being one of the favourite spots. There is, however, concern about signs of declining fish populations in the lagoon, the cause of which is thought to be the increasing encroachment of marine sediment in the lower reaches of the estuary (Day, 1981). Heydorn and Tinley (1980) suggest that the presence of the sediment in the mouth inhibits the tidal interchange of water and the movement of marine organisms in and out of the lagoon. They also suggest that the main reason for the presence of increased quantities of sediment is premature opening of the estuary mouth.

A major reason for the artificial breaching of the estuary mouth is that fields in the upper reaches of the estuary are flooded when the water level is high. Certain properties along the northern banks of the lagoon may also be flooded. The mouth has always been opened before the water level reaches such a height (Franks, unpublished data, Appendix 1), thus preventing flooding. Breaching of the sandbar is often undertaken illegally by private landowners. According to Franks the estuary has been artificially opened with bulldozers or spades, every year since 1948. The only year the estuary was not opened is 1973, when there was hardly any rainfall, and the water levels in the lagoon stayed very low.

The opening of the estuary mouth has ostensibly been controlled by the Caledon Divisional Council and the Forestry Department in the past. The Cape Department of Nature and Environmental Conservation (CDNEC) now controls the mouth and their policy is not to open the mouth artificially, but to allow the water level to rise sufficiently to break through naturally (J Neethling,

Director and I Visagie, Conservation Officer, CDNEC pers. comm.). This happened in October 1984 after which the mouth remained open until March 1985, and it reopened again in July 1985.

This study was initiated because the Klein River Estuary is becoming a major recreational centre. The subject of water levels and mouth openings has been a matter of controversy for a number of years.

It is felt that since artificial mouth openings probably adversely affect the sediment dynamics at the estuary mouth, which, in turn affects the fauna and flora of the estuary, an investigation into the feasibility of maintaining high water levels was necessary.

Although Noble and Hemens (1978) state that the state of knowledge on the Klein River Estuary is "good", the last extensive report on the system was completed in 1954 by F H Talbot, and there has been no research directed at the management of the estuary. Coetzee and Pool (1986) describe it as "a fairly healthy estuarine system despite water extraction in the catchment and some severe sedimentation in the mouth area".

It would be advantageous to propose a management policy for this estuary whilst it is in good condition, in order to keep it as a healthy system rather than let it become degraded before a management policy is formulated or remedial action is required.

2.3 Previous studies

Scott, Harrison and Macnae (1950) described the flora and fauna and the physical and chemical conditions of the estuary.

Talbot (1954) studied the biology of the white stumpnose (*Rhabdosargus globiceps*) and the other fish in the Klein River Estuary.

Sloman (1983) studied the sediment distribution and components of the sediments of the estuary.

Coetzee and Pool (1986) studied the physico-chemical conditions of the estuary.

Villiers, Jansen and Muller (1955) mapped the geology of the area.

Moll, Campbell, Cowling, Bossi, Jarman and Boucher (1984) mapped the vegetation of the area with the aid of Landsat satellite images.

CHAPTER 3

3 CATCHMENT CHARACTERISTICS

3.1 Area

According to the River Flow data 1960-1970 the catchment area of the Klein River is 600 km². Sloman (1983), however, stated that the catchment area varies between 740 - 870 km². Noble and Hemens (1978) report the catchment area to be 741 km², and Heydorn & Tinley (1980) state it to be 750 km².

3.2 Tributaries

The Klein River is a result of the combination of two smaller rivers, the Hartebees River and the Steenboks River. These two tributaries join to form the Klein River, approximately 50 km from the estuary mouth. The Hartebees River is the main tributary, and flows between two ranges, namely the Kleinriviersberg and the Steenboksberg. Its source is in the Kleinriviersberg (Fig. 3).

3.3 River Length

The length of the Klein River is taken to be the length between the source of the Hartebees River (the main tributary) and the mouth of the Klein River Estuary. This distance is approximately 93 km.

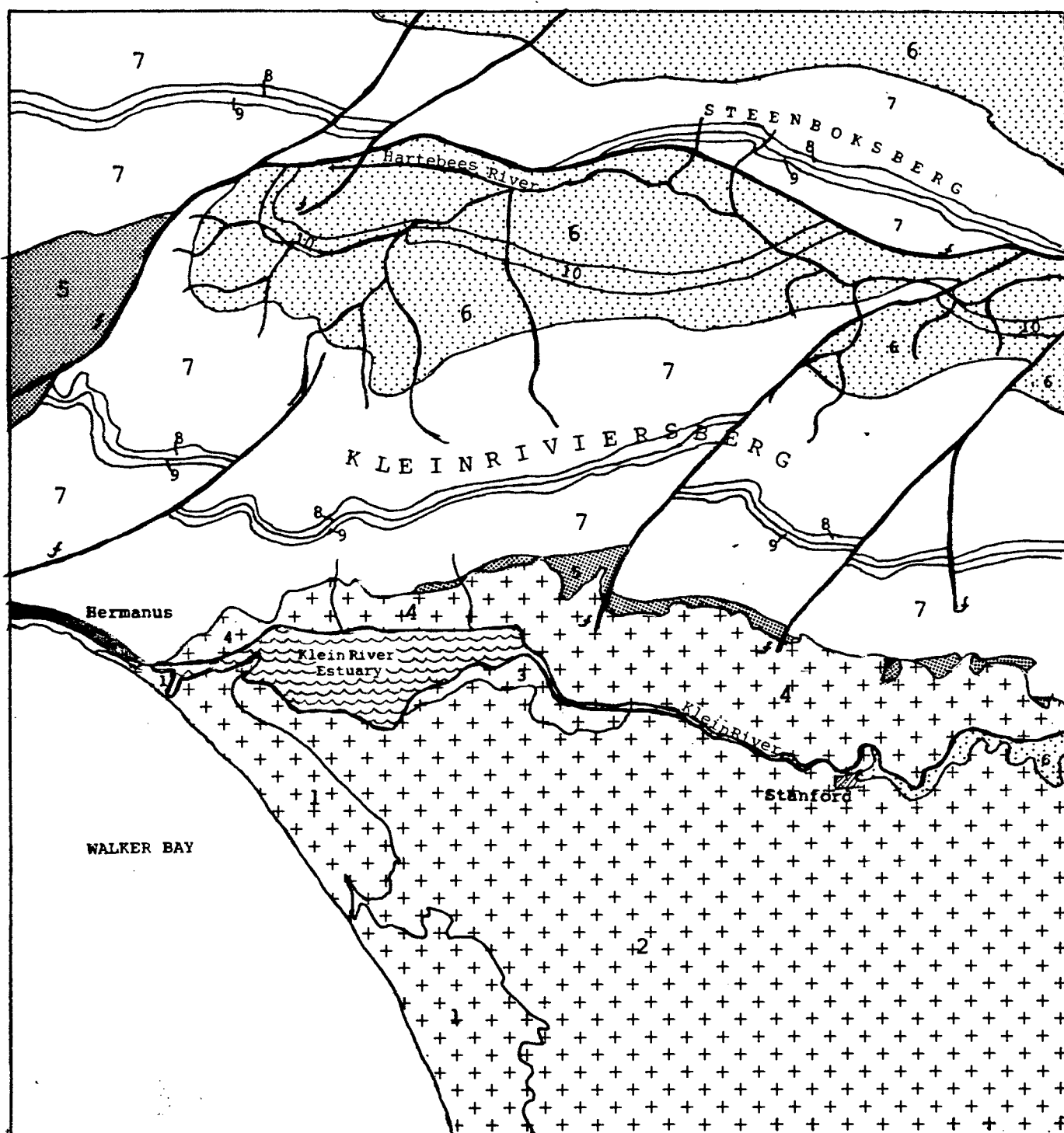
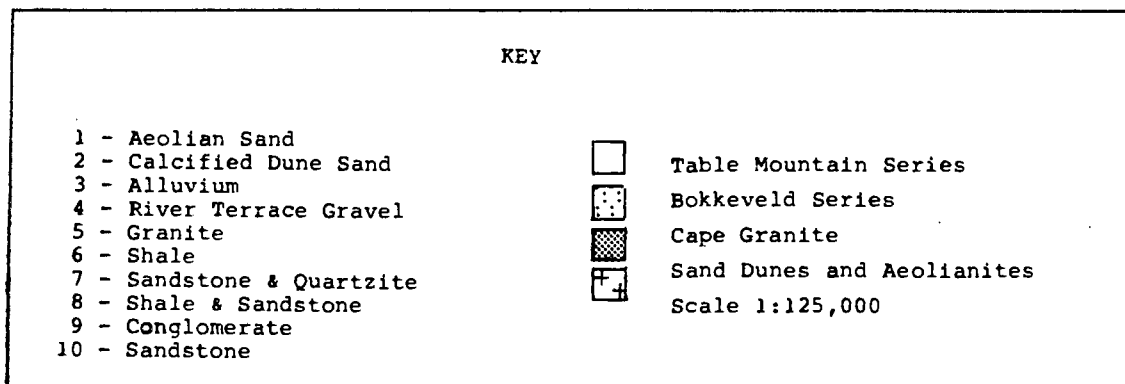
3.4 Geology

Fig. 3 shows the major geological formations around the Klein River Estuary and its catchment area. The three major geological groups in this area are the Table Mountain Series, the Bokkeveld Series and the Cape Granite.

The Steenboksberg and the Kleinriviersberg are the two major mountain ranges in the area and are composed of erosion-resistant Table Mountain sandstone. These mountains form the main catchment area of the Klein River. The valleys between

Fig.3 Geological map of the area surrounding the Klein River Estuary.

from the map published by the Government Printer, 1966.



these mountain ranges comprise Table Mountain group sandstone and Bokkeveld shales which are much less resistant to erosion than those of the Table Mountain Group. These valleys contain residual soils which are the product of weathering and erosion of the Bokkeveld shales and sandstones (Theron, 1983). The valleys are farmed and it is from these areas that the silt in the Klein River originates.

The few granite outcrops in the area are thought to provide certain clays and feldspars to the catchment area (Sloman, 1983).

The coastal dunes and aeolianites to the south of the estuary are partially vegetated and the calcified dunes are stable. The aeolian sands form an area of dunes which run along the whole of Walker Bay. This land is under the authority of the Directorate of Forestry. One of the functions of the Directorate is to stabilize and control mobile sand, and it is for this reason that sand dunes were stabilized with alien vegetation, the main species being *Acacia cyclops*. The dunes have been stabilized by indigenous vegetation since the beginning of this century, but the acacias were sown in the 1950s (J Van der Merwe, District Forestry Officer, Directorate of Forestry, pers. comm.). The long term plan for this area is to eradicate the acacias and re-establish the indigenous vegetation. To date, 400 ha of acacias have been cleared.

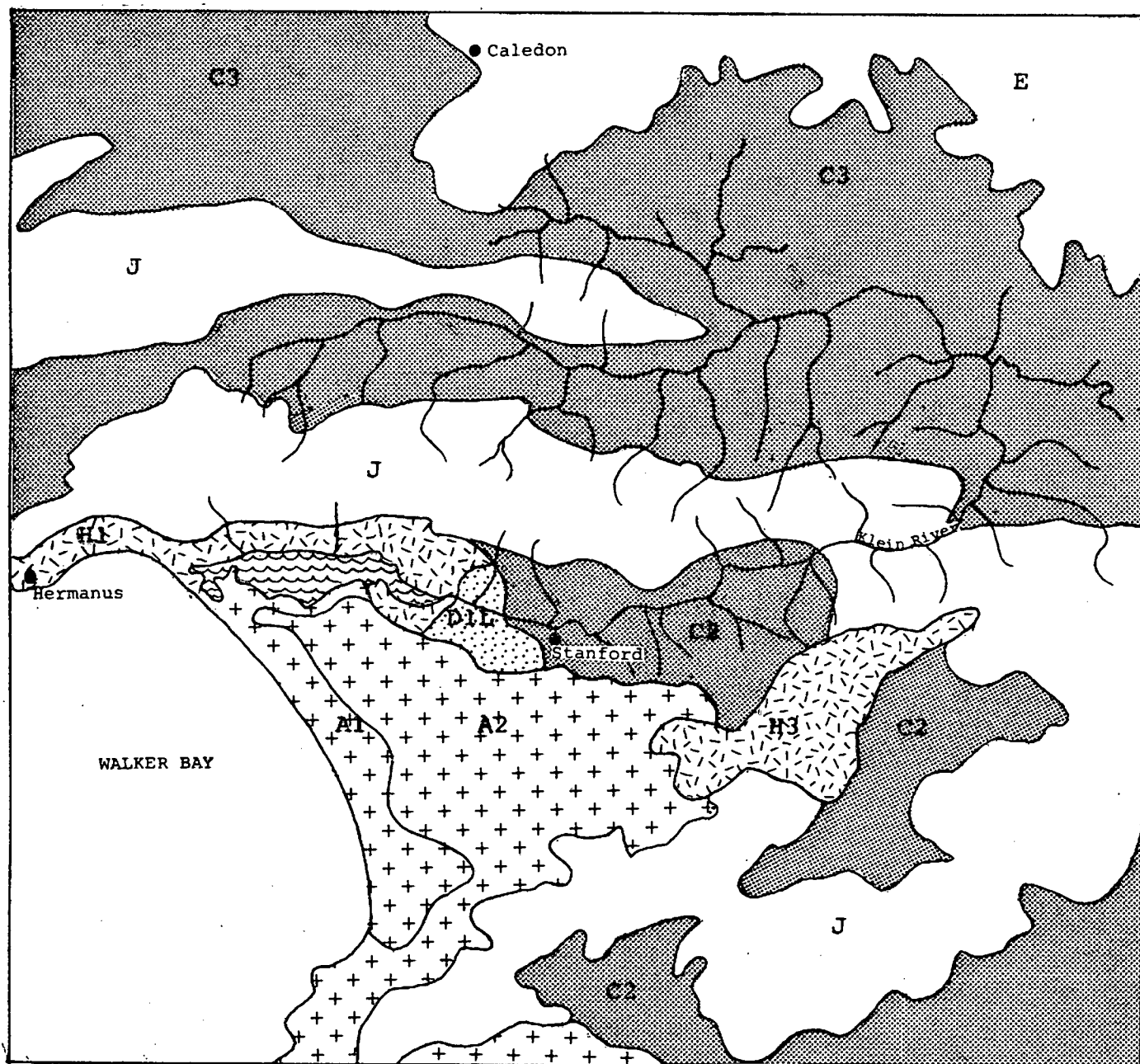
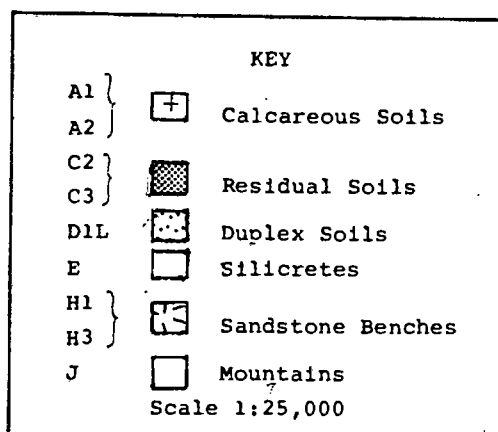
Since the mountains in the area are composed of erosion resistant Table Mountain sandstone the runoff is quite high, particularly in the upper catchment. However, the calcified dunes to the south of the estuary have a gentler gradient and the runoff in this area is almost nil.

3.5 Soils

The soils surrounding the lagoon and in the catchment area are shown in Fig. 4. The soils in this region have been divided into 10 units by Scholms *et al.* 1983. The soils to the south of the lagoon are mainly calcareous coastal sands and soils on sandstone benches.

Fig. 4 Soils in the catchment area of the Klein River.

From Scholms, Ellis and Lambrechts, 1983.



Unit A is divided into grey calcareous sands (A_1) and calcareous sands and lithosoils (A_2). The grey calcareous sands are mainly mobile dunes, some of which have been stabilised by alien vegetation. The lithosoils are very shallow as this area is composed of stable, calcified dunes which are vegetated with south coast strandveld and have not developed a deep soil.

The unit H is subdivided into sandy podzolic hydromorphic soils, some of which are found at an elevation of 30m (H_1) and some at 100-200m (H_3). The soils are locally derived and tend to be highly leached and fairly well weathered.

The soil types in the catchment area to the north and east of the estuary are residual soils (unit C) and mountain soils (unit J). Unit C is divided into duplex loams (C_2) and poorly developed residual soils (C_3). The duplex loams are acidic with low nutrient levels and are found in areas of fairly high precipitation.

None of the soils in the area of the Klein River is very fertile, most of them being shallow, sandy and well leached. The deepest soils are the duplex loams between Stanford and the Klein River lagoon.

From Fig. 4 it can be seen that there are two main soil types found in the catchment area; poorly developed residual soils and the sandy lithosoils on the mountains. The residual soils are formed by *in situ* weathering and tend to be in the valleys between mountain ranges. They are fairly deep soils, but not particularly fertile.

The soils found on the mountains in the south western Cape are highly leached, shallow, sandy lithosoils (J) with low agricultural potential since they contain few nutrients and allow for a fairly high run-off from the mountains.

The two remaining soils in Fig. 4 are Duplex soils (unit D) and silcretes (unit E). The subunit of D are fine grained, duplex loams (DIL) which contain a high percentage of swelling clays. This area is liable to become waterlogged during periods of high rainfall.

The silcretes around Caledon are moderately weathered and occur on rolling landscape. (Scholms et al 1983).

Since the soils in this area are fairly porous (King et al, 1979) most surface water percolates into streams. This indicates that the soils, especially those in the mountain areas, have a low erodibility, especially if covered with fynbos vegetation. The cultivated soils in the valleys are, however, susceptible to erosion because they are often exposed during cultivation.

Since the soils in the mountains are shallow and highly leached, they will produce a fairly high runoff but the soils in the valleys are deeper and absorb more of the runoff water. The cultivated areas will have a slightly higher runoff

3.6 Vegetation

The richest natural flora in the catchment area of the Klein River is found in the Kleinriviersberg and the mountain range to the north of the Kleinriviersberg which includes Steenboksberg and Shaws mountain.

Fig. 5 is taken from Moll et al (1984) and shows the main vegetation types. According to Moll et al (1984), the vegetation on these mountains is mesic mountain fynbos. This vegetation type has three main elements, restioid, proteoid and ericoid, and there is a high degree of species richness in the mountains. The vegetation cover is good but there is evidence of alien intrusion into the natural vegetation of this area.

The white areas in Fig. 5 indicate either cultivated land or dense alien vegetation. The land to the south of the estuary along Walker Bay includes formerly mobile dunes. These have been stabilized with alien species such as *Acacia cyclops*, *A. saligna* and *A. longifolia*. This land was planted with alien vegetation in the 1950s by the Directorate of Forestry who are now attempting to clear the area and restore it to its natural state. Fig. 6 shows the mouth area before, during and after the dune stabilization.

Fig. 5 Vegetation types in the area of the Klein River Estuary. 22

From Fynbos Biome Map, 3319 Worcester, 1980. Scale 1:250 000

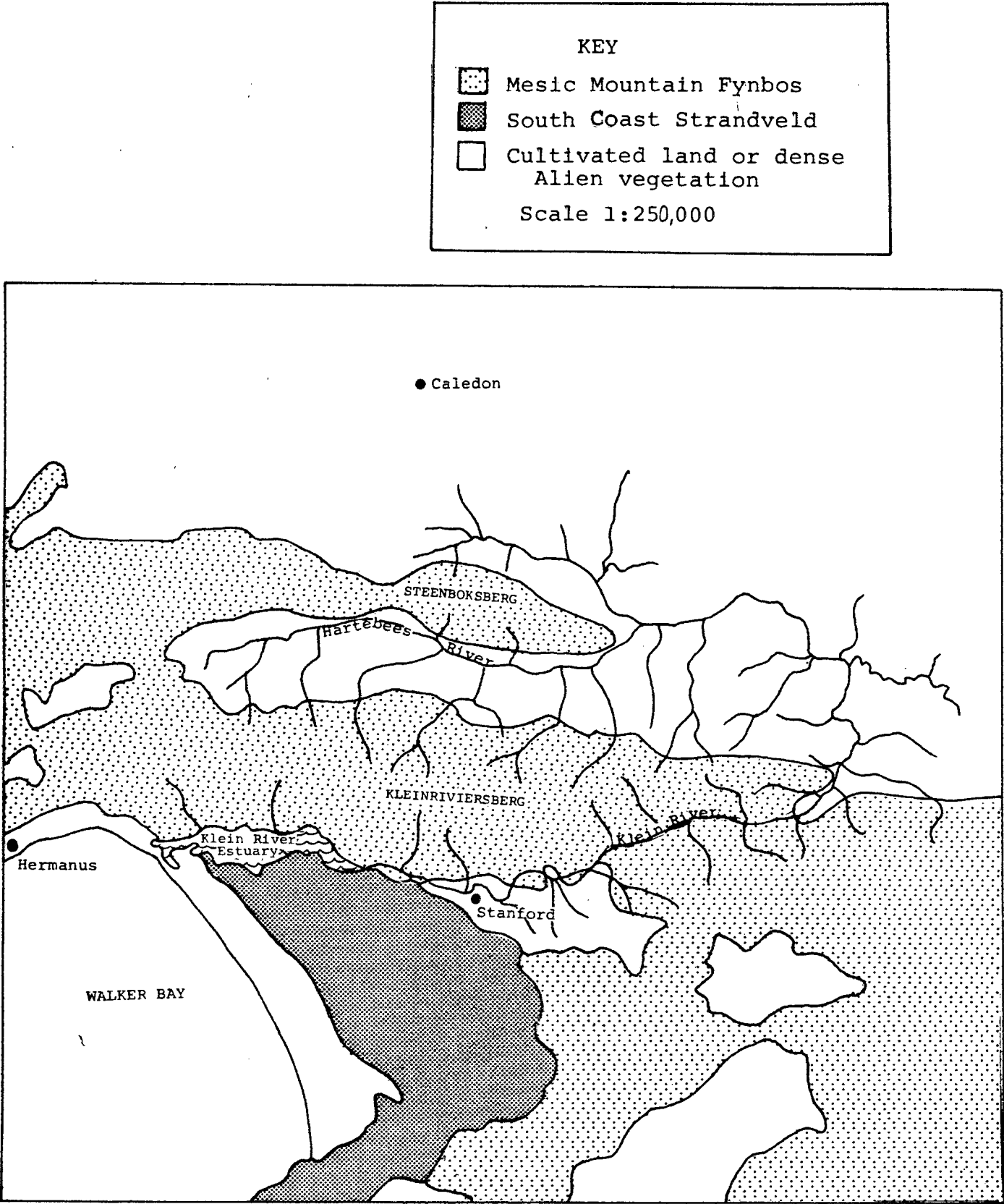
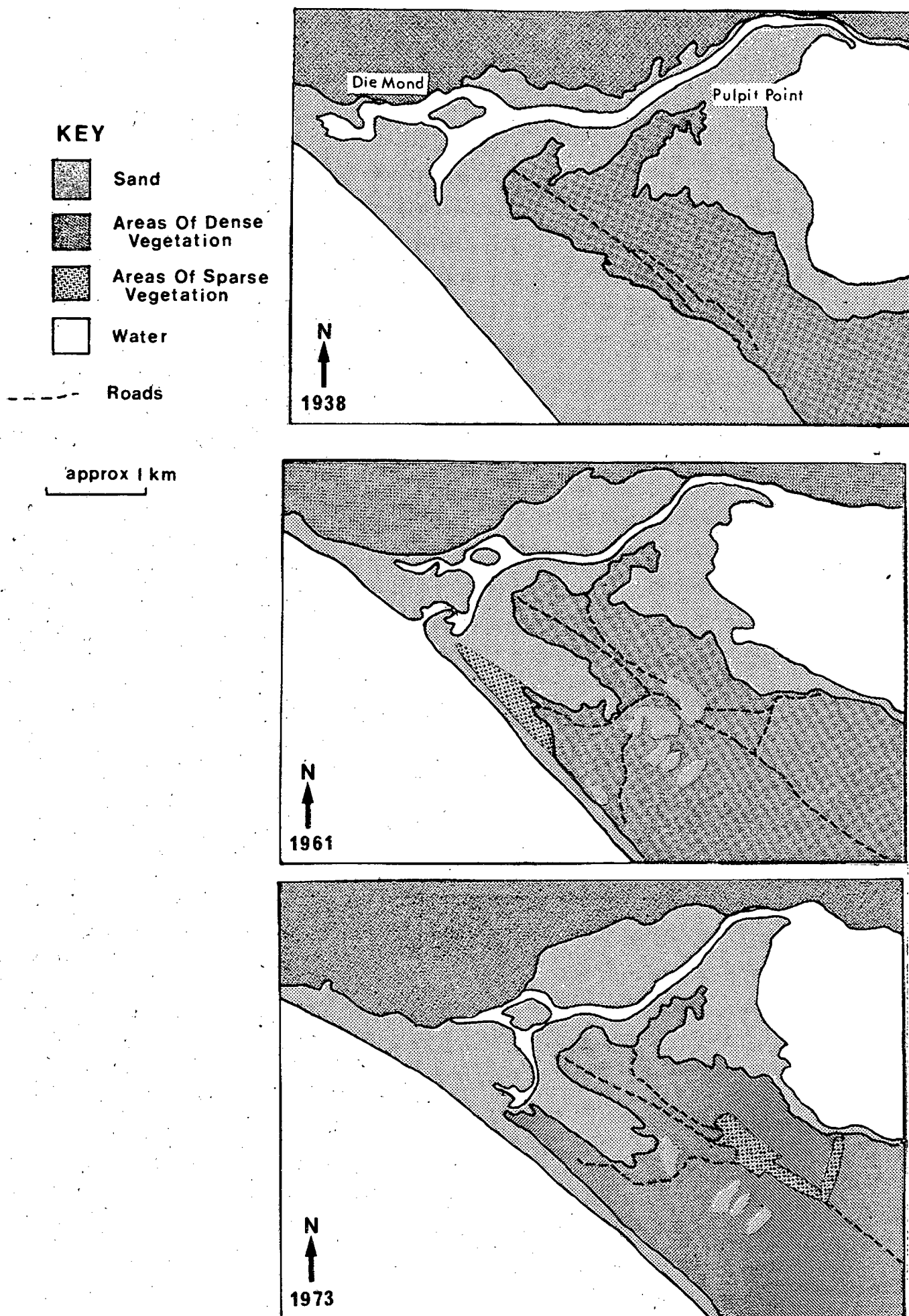


Fig. 6 Vegetation of the dune at the estuary mouth.

From aerial photographs, Dir. Surveys, Mowbray.



Before the dune was stabilized (1938) the area of sand was much more extensive to the south of the lagoon. The total area stabilized is more extensive than is suggested by the 1961 picture in Fig. 6, but this gives a good idea of the length of the dune next to the estuary mouth. By 1973, the dune had been partially eroded by eastern mouth openings and the channel in the eastern side of the mouth area had become established. The vegetation of this dune has affected the position of the estuary mouth by confining it to a smaller area of shoreline. This could affect the transport of sediments out of the estuary.

The land around Stanford is cultivated, as is the land between the two mountain ranges. Fig. 5 shows that the majority of land in the catchment is either cultivated or mesic mountain fynbos. According to Moll et al (1984) mesic mountain fynbos occurs on seasonally waterlogged sites which suggests that there is poor drainage and fairly low runoff in these sites. The cultivated land, however, has a higher runoff, although the majority of this land is used for grazing (S van Rooyen, Agricultural Extension Officer, Caledon. pers. comm.)

The river flows through this cultivated land and for the majority of its length is infested by alien vegetation. There are large stands of mixed aliens such as *Acacia saligna*, *A longifolia*, *A mearnsii*, *Albizia lophantha* and *Eucalyptus lehmanni*, which are actually growing in the river. These aliens have become so dense that they pose a serious problem because the flow of the river is being obstructed. This is thought to cause abnormally high river water levels during periods of heavy rainfall.

The other main vegetation type is South Coast Strandveld which occurs to the south of the estuary. The main elements in this vegetation type are succulents, broad leaved deciduous plants and evergreen shrubs. The vegetation cover is good but there are many alien plants in this area. The runoff in this area is low, there is little cultivation and the gradients are gentle.

3.7 Climate

The general climate in the south western Cape is Mediterranean with no extremes (Tyson, 1969). The mean annual temperature is 17°C and the mean rainfall is approximately 738 mm per annum (Fig. 7).

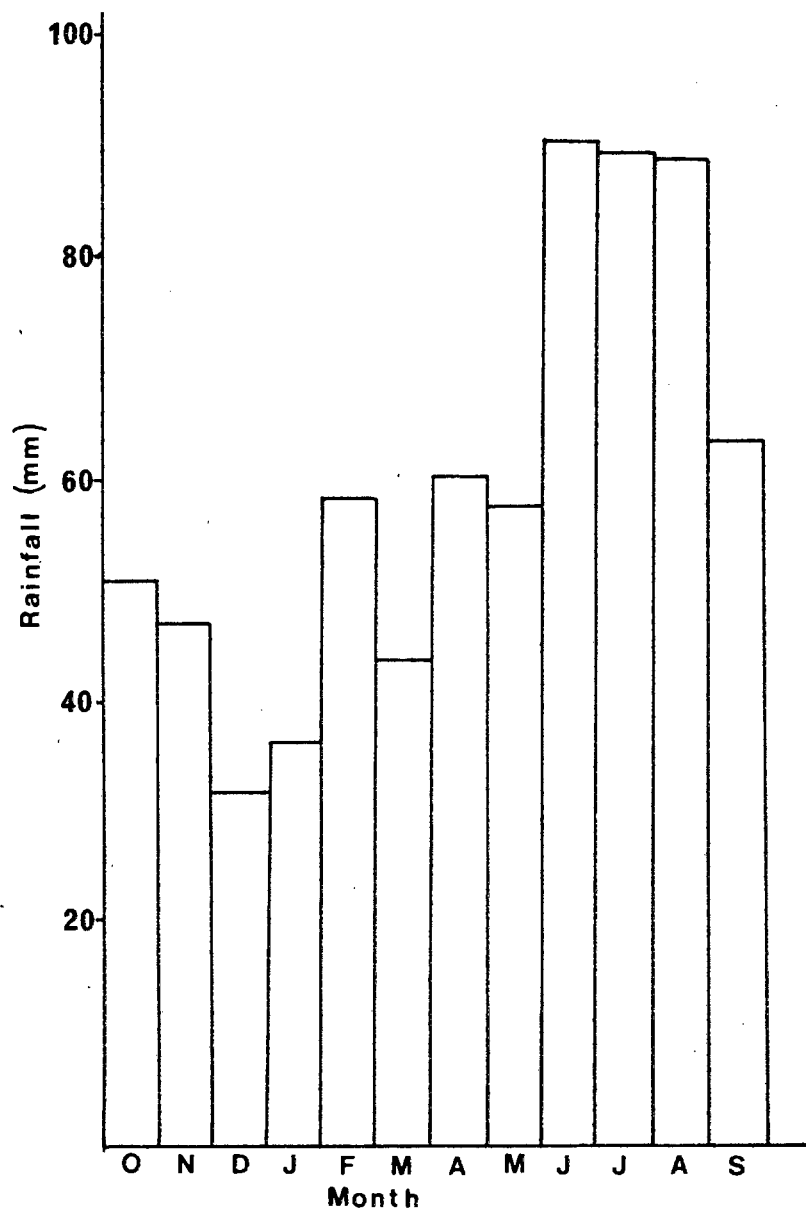
Wind plays an important role in the dynamics of the Klein River Estuary. When the mouth of the estuary is closed, the water is mixed by the wind which keeps it circulating and well oxygenated. The Kleinriviersberg deflect the prevailing winds so that they blow up or down the long axis of the estuary. In the summer, the south easterly winds are deflected and become easterlies tending to push the less saline water from the river further down the estuary towards the sea. The opposite occurs in the winter when the north westerly winds prevail and are deflected westward, thus pushing the more saline water towards the upper reaches of the estuary. This effect is only noticeable if saline water can enter the estuary. If the mouth is closed the north westerly and south easterly winds result in well mixed water.

3.8 Rainfall and Runoff

Mean rainfall at Voelklip (the Forestry Station at the estuary mouth) over the years 1973 - 1983 is presented in Fig. 7.. The highest rainfall occurs in June, July and August, ie the winter. However, there is a strong orographic control over rainfall in this area, and the rainfall in the catchment area is likely to have a different pattern from that of the coastal area. Unfortunately, there are no detailed records of rainfall in the catchment area, so a comparison cannot be made, but judging from the river flow patterns (Fig. 8), there is likely to be a peak in rainfall in August. According to Day (1981) the Hermanus district has an average rainfall of 510 mm per annum.

Rainfall data from Voelklip (recorded at the Forestry Station near the mouth) was compared with estuarine water

Fig. 7 Average monthly rainfall at Voelklip.
1970 - 1980.



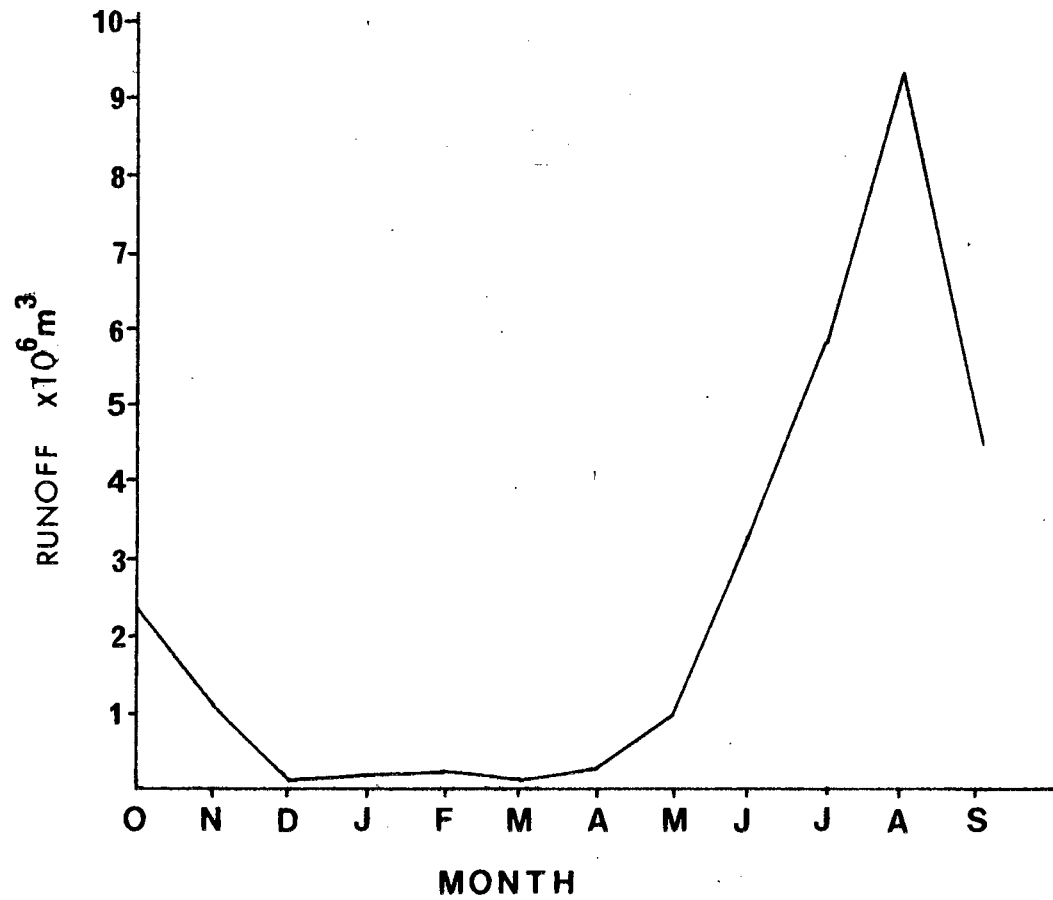
levels to determine whether there was a significant increase in water level. The rainfall will only directly affect the water level if the mouth is closed, therefore, the level was examined in months when the mouth was closed, and it was found that rainfall in the Voelklip area had no significant effect on the water level. Table 1. shows the effect of rainfall in August, 1984.

Table 1. Rainfall at Voelklip and its effects on water levels.

Date of rain	Rainfall (mm)	Level before rain (m)	Level after rain (m)
3/8/84	1.2	3.507	3.508
6/8/84	9.9	3.541	3.540
13/8/84	7.1	3.561	3.567
16/8/84	7.7	3.580	3.580
24/8/84	2.0	3.610	3.610
26/8/84	12.4	3.610	3.610

From this table it can be seen that the largest rise in water level (6mm) occurred on 13/8/84, when 7.1mm of rain fell, but when 9mm fell on 6/8/84, the water level actually fell by one millimetre. This suggests that river flow actually directly affects water levels in the lagoon more than rainfall. However, rainfall will indirectly cause a rise in water levels by increasing the runoff, which will increase the river flow and thus cause a rise in water level. There will be time lags between these events so the effect of rainfall will not be immediately evident. The river flow in this month was low compared with the average river flow for August shown in Fig. 9. The maximum rate of rise occurred in June 1981 when the estuary closed on 27th June and re-opened on 25th July. The level rose 1.1 m in 23 days, which a rate of 39 mm per day. The runoff and rainfall were both high in 1981 as can be seen in Figs. 8 and 9.

Fig. 8 Average monthly runoff,
1970 - 1980.



Maximum yearly runoff,
1973 - 1984.

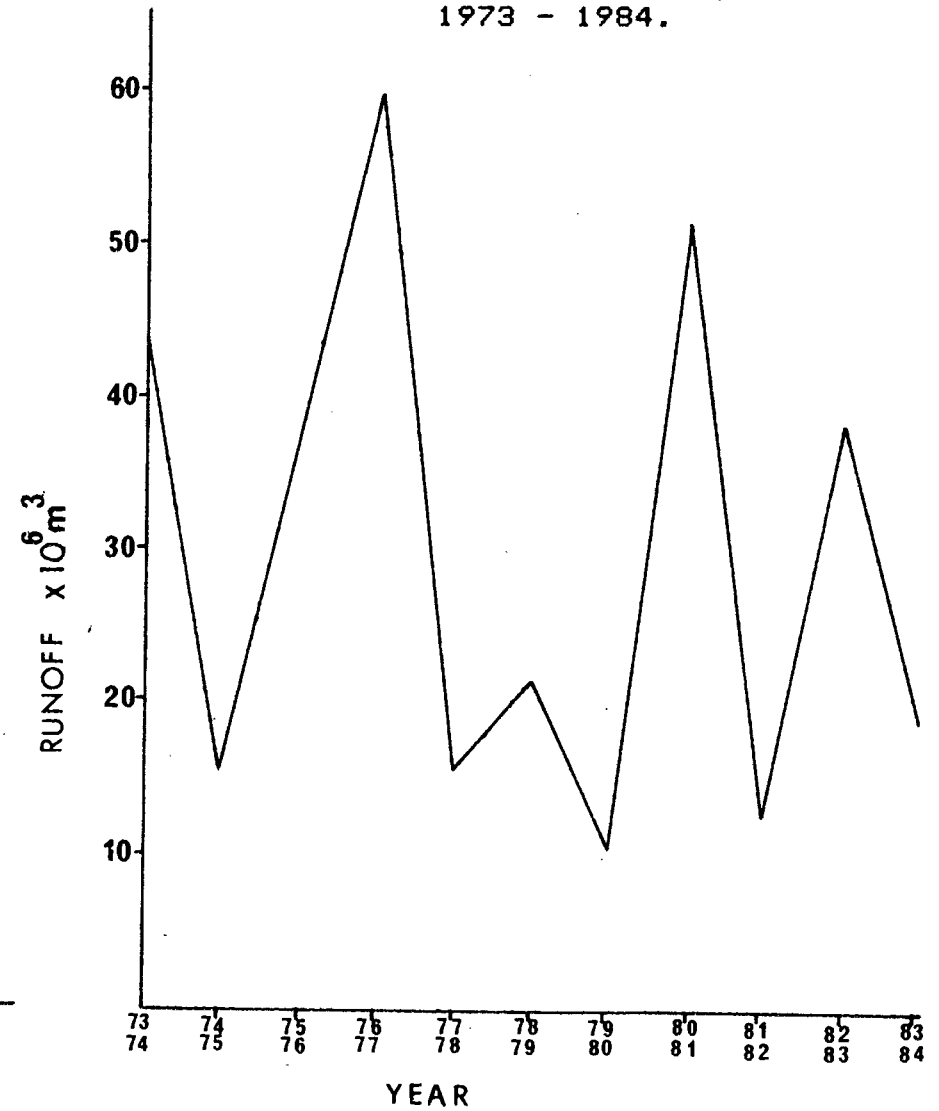
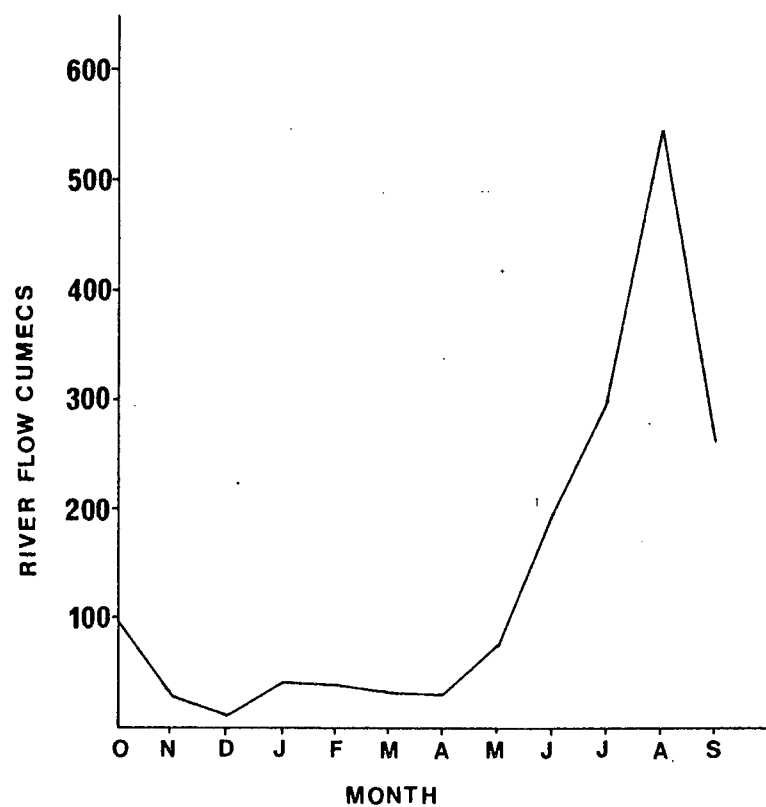
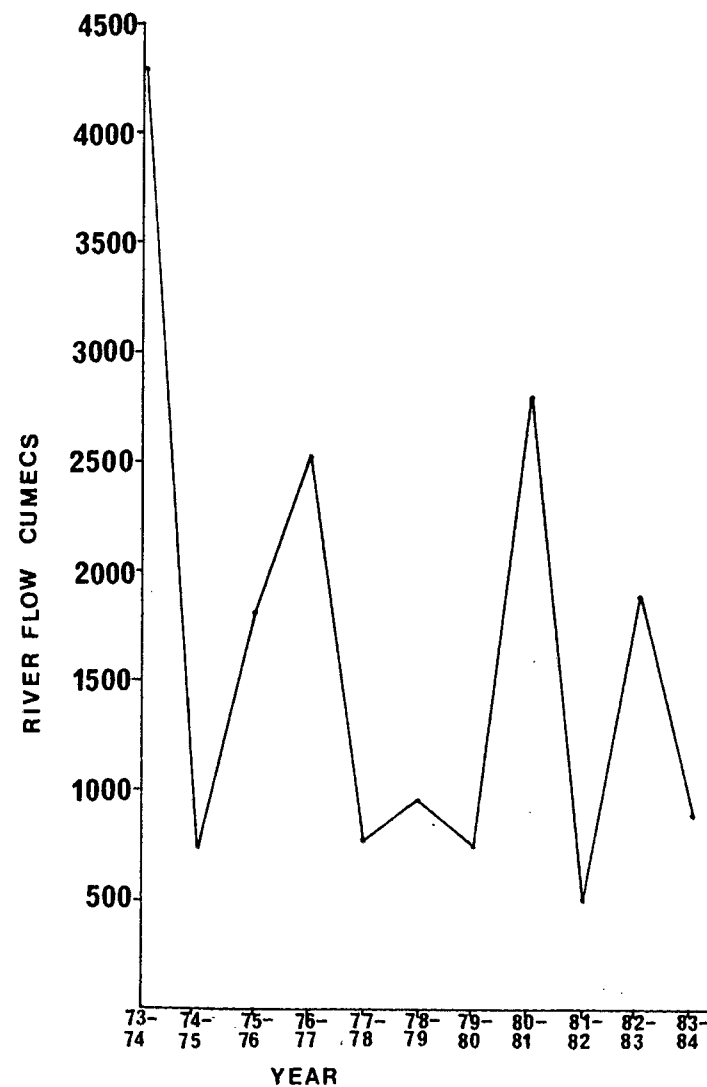


Fig. 9 Average monthly river flow,
1970 - 1980.



Maximum yearly river flow,
1973 - 1984.



It is concluded that rainfall from the Voelklip area does not significantly affect the water level because the main catchment area for the estuary is on the opposite side of the Kleinnriviersberg. The rainfall in this area and the runoff are all included in the data for the total seasonal flow of the Klein River (Hydrological data 1973-1974).

The average runoff in this area is $29.41 \times 10^6 \text{m}^3$ per annum (Hydrological data, 1973 - 1984), but this runoff varies considerably from year to year (Fig. 8). These data were obtained from the hydrological gauging station (G4M06) on the Klein River, situated at $34^\circ 24 \frac{1}{4}'\text{S}$, $19^\circ 35 \frac{3}{4}'\text{E}$. This is approximately six kilometres upstream from Stanford. Noble and Hemens (1978) state that the mean annual runoff is $96 \times 10^6 \text{m}^3$, but Day (1981) states it to be $6 \times 10^6 \text{m}^3$.

The average monthly runoff from 1973 - 1984 is shown in Fig. 8. There is a large peak in August, ($9.29 \times 10^6 \text{m}^3$) when the rainfall is highest.

3.9 River Flow

The monthly river flow data are presented in Fig. 9. The flow measurements were obtained from the gauging station G4M06, approximately six kilometres upstream from Stanford. It can be seen that peak river flow occurs in August (approximately $540 \text{m}^3/\text{sec}$), which corresponds with the high rainfall at this time.

3.10 Land ownership and uses

This summary is based on information obtained from Mr S van Rooyen, Agriculture Extension Officer at Caledon.

The catchment is dominated by privately owned farms averaging 400 ha in extent. The high land on the mountains was used for grazing, but some farmers are turning this land over to wild flower growing since it is mostly natural fynbos vegetation in these areas. The valleys in the catchment area are used for grazing or for wheat and barley production. The farms further downstream, where the land is slightly flatter, use the land along the river for growing

vegetables. It is these fields that sometimes become flooded during periods of high rainfall. The soil in the area along the river can become waterlogged during the winter (Scholms et al 1983).

3.11 Siltation

According to S van Rooyen (pers. comm.) there is little soil erosion in the catchment, since the farms do not have extensive areas under cultivation. However, some silt originating from riparian lands is washed down the river. The main reason for this being the presence of extensive, dense stands of alien vegetation actually growing in the river. These stands obstruct the river causing it to burst its banks during periods of high rainfall when the flow is at its maximum. The water then carries the soil from adjoining fields downstream and deposits it where the river enters the lagoon. These deposits have formed a small fluvial delta in the upper reaches of the estuary.

CHAPTER 4

4. ESTUARINE CHARACTERISTICS

4.1 Physical characteristics

4.1.1 Estuary type

The definition of an estuary proposed by Pritchard (1967) is widely accepted:

"An estuary is a semi-enclosed body of water which has free connection with the open sea and within which, sea water is measurably diluted with fresh water derived from land drainage."

Unfortunately, Pritchard's definition excludes most southern African and southern Australian estuaries which are closed for part of the year by a sand berm and which can become hypersaline during the dry season. Day (1980) amended Pritchard's definition to eliminate these difficulties:

"An estuary is a partly enclosed body of water which is either permanently or periodically open to the sea and within which there is a measurable variation in salinity due to the mixture of sea water with fresh water derived from land drainage".

This definition is more applicable to South African estuaries. The Klein River Estuary is often referred to as a 'lagoon' since it is cut off from the sea during the dry season, by a sand berm. The term lagoon has no fewer than eight definitions depending on the form of the barrier and on the type of coast. For the purpose of this study, Day's definition of an estuary will be adopted. The Klein River Estuary is a closed estuary with periodic (artificial) openings of the estuary mouth through the sand berm. These artificial openings have taken place virtually every year since 1948 (Franks, unpublished data). Noble and Hemens

(1978) classify the Klein River Estuary as 'lagoonal', because of the extensive lagoon behind the sand berm.

4.1.2 Area and Volume

The lagoon is approximately 9 km long and 2 km wide at the widest point (1:10 000 orthophotos, sheets 3419 AD17 and 3419 AD18). The area of the lagoon changes according to the water levels, but can fluctuate from 4.27 km² to 11.28 km². The volume of the lagoon can fluctuate from 4.08 x 10⁶m³ to 24.41 x 10⁶m³. Various morphological parameters are presented in table 2. The calculations for these parameters are presented in Appendix 2.

Table 2. Morphological parameters.

PARAMETERS	WATER LEVEL		
	Highest	Middle	Lowest
Height (m)	3.825	2.186	1.658
Area (km ²)	11.28	5.60	4.27
Volume (m ³)	24,41 x 10 ⁶	8.87 x 10 ⁶	4.08 x 10 ⁶
Shoreline length (km)	26.83	18.38	17.46
Maximum Depth (m)	4.625	2.986	2.485
Filling Time (days)	301.7	109.63	50.4
Maximum Open Water length (km)	7.45	6.60	5.20
Maximum Open Water Breadth (km)	2.00	1.85	1.75

4.1.3 Geomorphology & Bathymetry

Fig. 10 shows the geomorphology of the area. The northern shores are steeply sloping and are composed of sandstones of the Table Mountain Group of the Kleinriviersberg. The

Fig 10. Cross section of the upper reaches of the estuary showing the Geomorphology of the area.

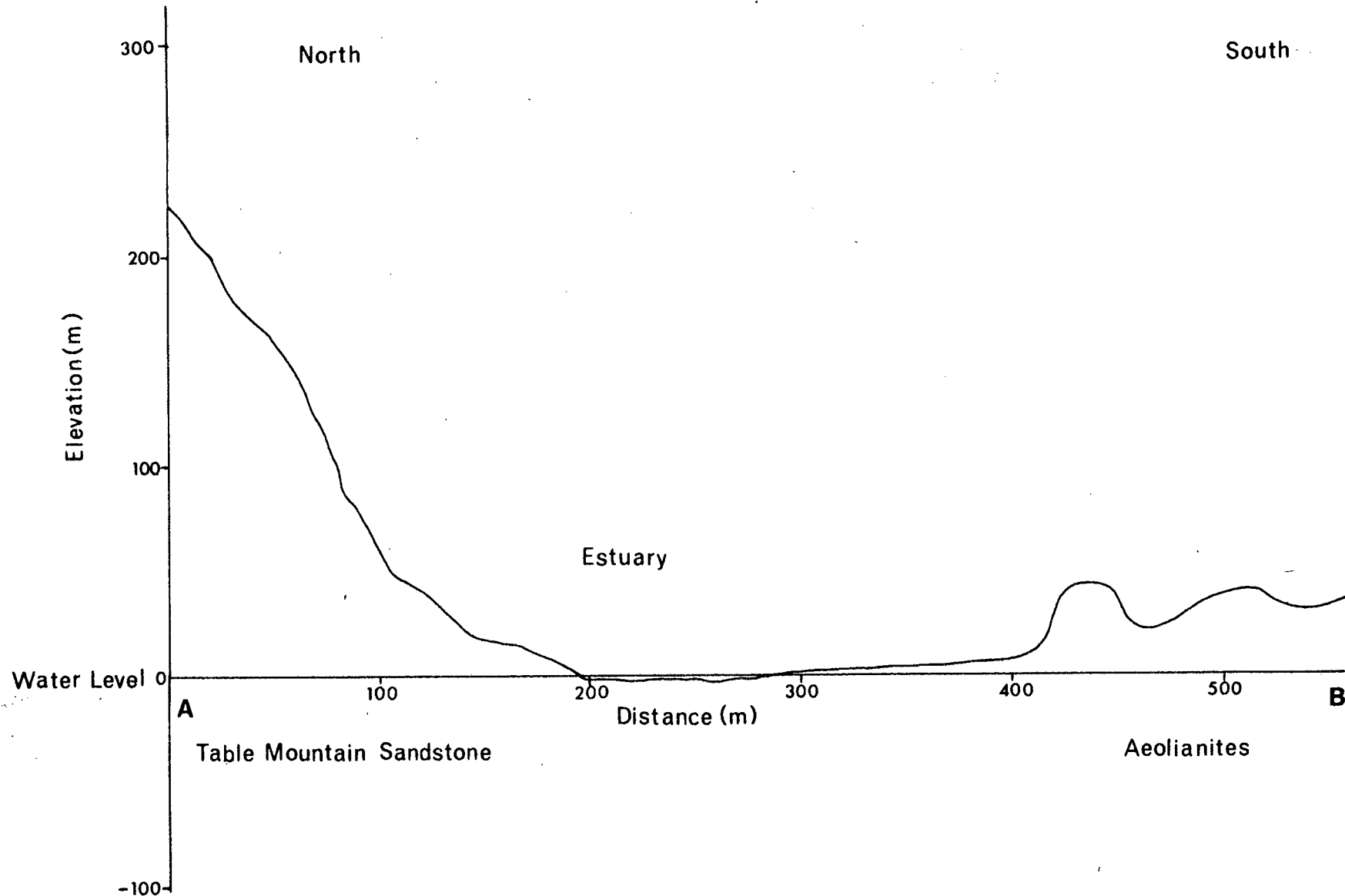
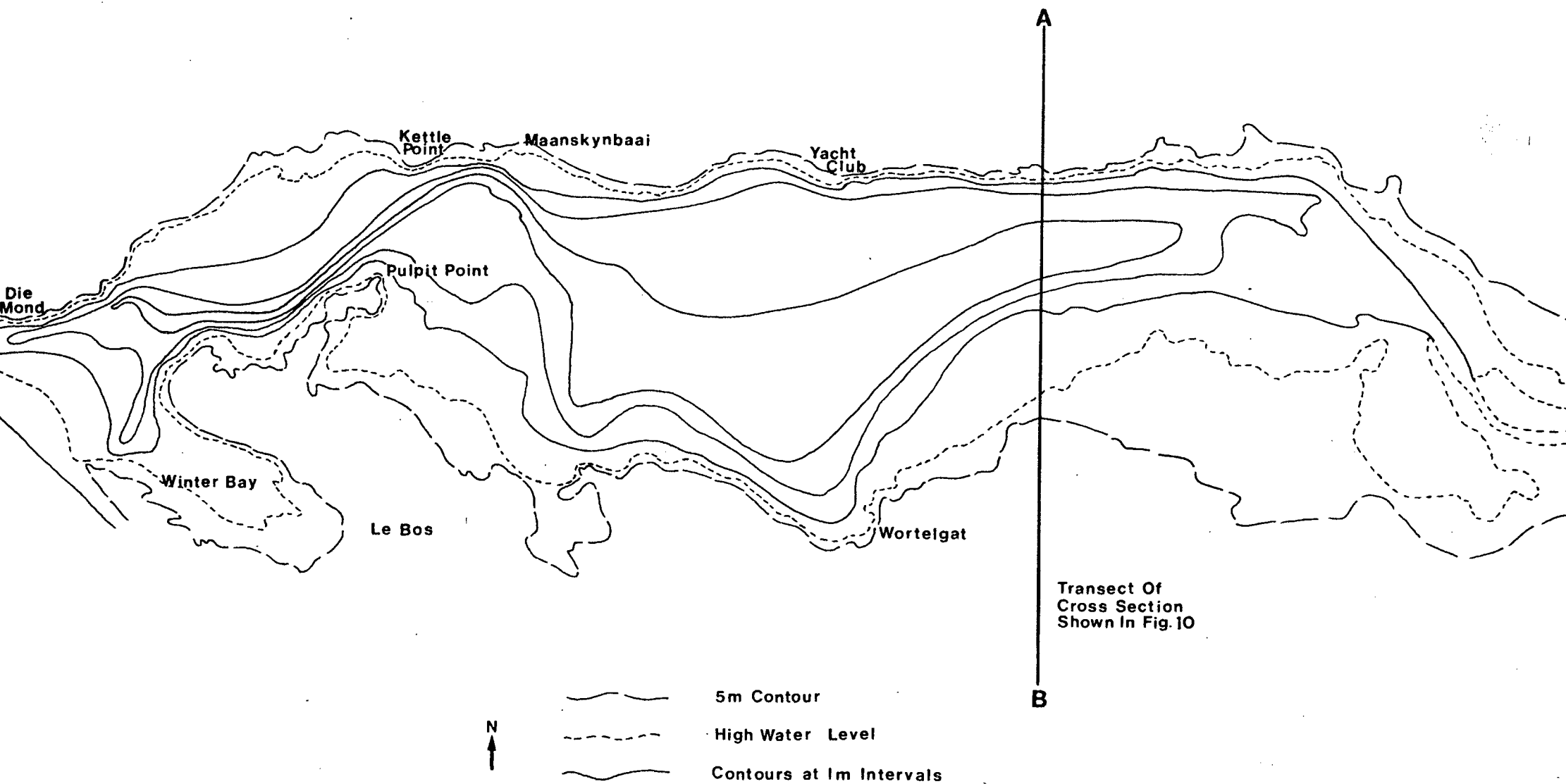


Fig. 11 Bathymetry of the Klein River Estuary.



Scale approx 1:23 000

southern shores are much less steep, being composed of calcified dunes and aeolianites.

An approximate bathymetric chart of the lagoon was prepared by Sloman (1983), but there has not been an accurate and detailed bathymetry plotted. Sloman's data in conjunction with data gathered by the present author in 1984 at a similar water level, was used to plot a more detailed bathymetric chart (Fig. 11). Stereo aerial photographs from 1961 and 1973 were also used to help plot the position of the channels and the contours on the southern shores. The bathymetry was plotted on an orthophoto map (Sheets 3419 AD17 and AD18 scale 1:10 000) of the estuary and has been reduced to a scale of approximately 1:23 000.

The purpose of plotting the bathymetry is to enable comparisons to be made. Although the values for the area and the volume are only approximate, they give some idea of the configuration at various water levels.

4.1.4 Bottom Sediments

The sediments of the Klein River Estuary have three sources, riverine, marine and from bank erosion (Dr van Heerden, NRIO, Stellenbosch, pers. comm.). In the past another source could have been aeolian, but the dune fields to the south of the estuary were artificially stabilised in the 1940s. These are now heavily vegetated and are unlikely to be a significant source of sediments entering the estuary. Willis (1985) states that strong gales occur during summer when the water levels in the Bot River Estuary are low. The gales transport beach sands into the estuary, and although wind-blown sand moves easily over dry sediments, it becomes trapped on reaching wet sediments or water. This could be the extent of aeolian transport of sediment in the Klein River Estuary since large areas of sand are exposed during low water levels. This aeolian transport would only occur during the winter when the winds are westerly and would thus blow sand from the beach into the estuary.

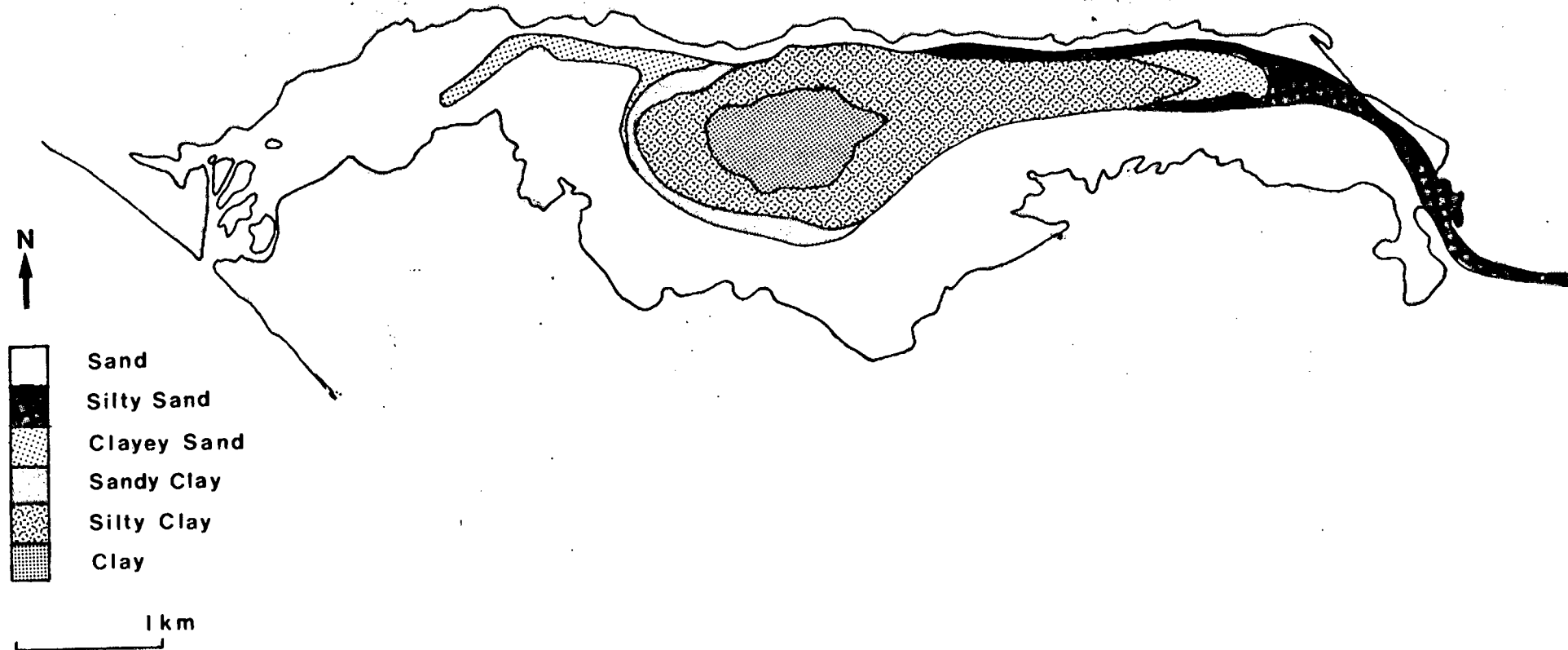
Another source of sediment is from overwash over the sand berm at the estuary mouth which can contribute significantly to the sediments in the mouth area (van Heerden pers. comm.). According to van Heerden (1985), the overwash in the Bot River Estuary is large enough to contribute towards landward progradation of the dune barrier. A similar situation could develop in the Klein River Estuary.

Sloman (1983) mapped the sediments of the Klein River Estuary using the Shepard (1954) classification of sediment types (Fig. 12). The sediments range from sand through to silt and clay particles with a particle size range of 1-3 phi, the sand being distributed at the mouth of the estuary, around the southern banks and where the river enters the estuary. The finer grained clays occur in the centre of the lagoon in the deeper water.

The riverine sediments are present in the upper reaches of the estuary and are deposited when the turbulent fresh river water combines with the more tranquil saline estuarine water (Dyer, 1979). A small fluvial delta has formed in the upper reaches of the estuary, consequently the water in this area is shallow, even at high water levels. The river channel is deep and well established, but shallows rapidly on entering the lagoon and meanders over the delta and shallow sediments in this area.

An ebb-tide delta is formed seaward of the estuary mouth when the mouth is open, this is the result of sediment being washed out of the estuary and into the sea on ebb-tides (Dr. Swart, NRIO, Stellenbosch, pers. comm.). This delta is reworked and eventually removed by marine currents although some sediment is transported up the estuary. The exact nature of the marine currents is not known, but long-shore drift probably plays an important part in the removal of the sediments. The National Research Institute for Oceanology at Stellenbosch is currently carrying out a research project (the Walker Bay Study) which aims to elucidate the sediment regime in the marine environment adjacent to the Klein River Estuary mouth.

Fig. 12 Distribution of sediments in the Klein River Estuary.
From Sloman 1983.



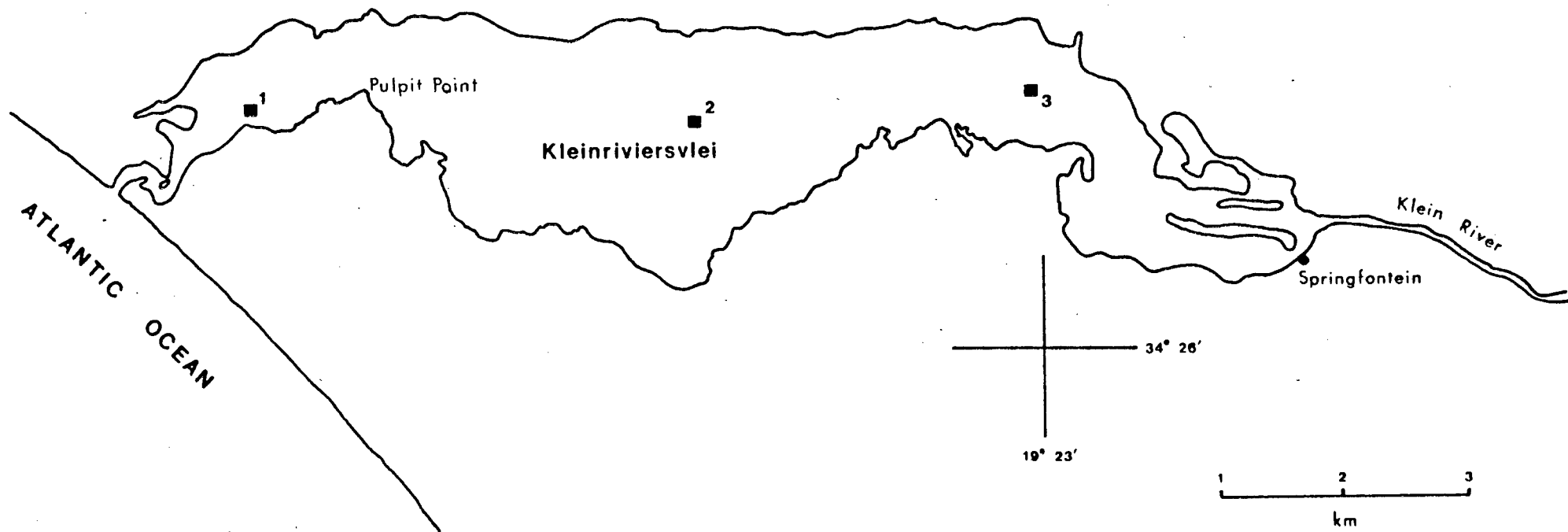


Fig. 13 Sample sites used by Coetzee and Pool, 1986.

A flood tide delta forms in the lower reaches of the estuary when the mouth is open (Swart, pers. comm.). This area has become the cause of some concern since it is not reworked to a great extent and as a result, there is an accumulation of sediments in the estuary mouth. There is a well established channel through these sediments (see Fig. 11, which shows the bathymetry of the estuary) which is always in the same place, running from Kettle Point on the northern bank, across the estuary towards Pulpit Point on the southern bank. The reason for this is the presence of a band of rocks which cuts across the lagoon and forces the channel to remain in the same position (van Heerden pers. comm.).

4.2 Physico-chemical characteristics

Most of the following data has been taken from Coetzee and Pool (1986).

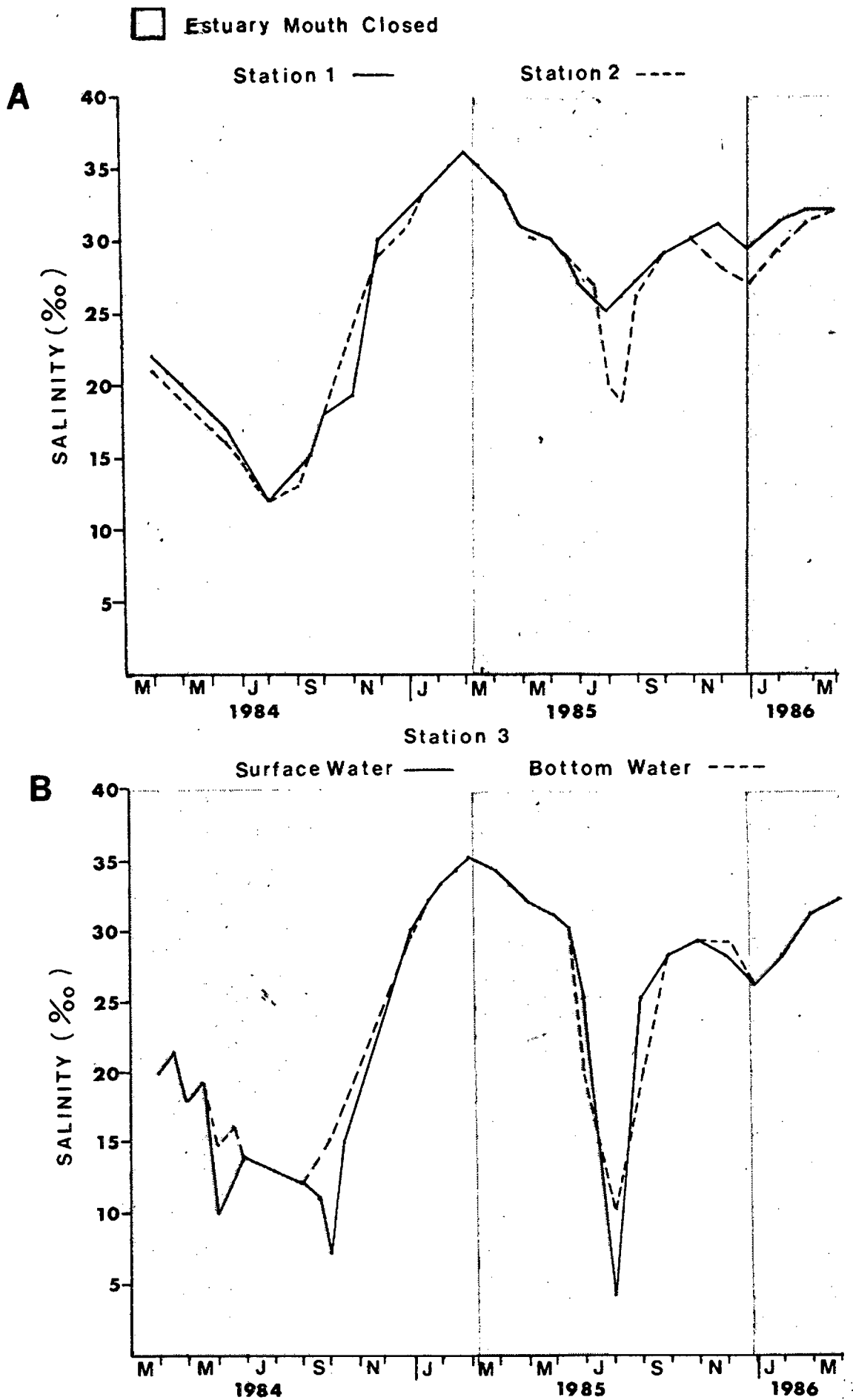
4.2.1 Salinity

Most of the fresh water entering this estuary comes from the Klein River and, during the winter, from small streams draining the Kleinriviersberg on the northern bank of the estuary.

The salinity of the estuary varies, depending on the time of year and whether the mouth is open or closed. Coetzee and Pool (1986) measured salinities ranging from 12 - 36 parts per thousand (ppt) in the lower reaches of the estuary and 4 - 35 ppt in the upper reaches (approximately 5 km from the mouth). Fig. 13 shows the positions of the three stations used by Coetzee and Pool. Fig. 14a shows the salinities at stations one and two, and Fig. 14b the surface and bottom salinities at station three.

Coetzee and Pool noted that the salinity values tended to decrease when the mouth was closed during the winter months, but increased when the estuary was closed during the summer months in 1986 (Fig. 14). This increase is expected and is due to high summer evaporation and low freshwater input. The salinities also tend to rise, when the mouth of the

Fig. 14 Salinity in the Klein River Estuary,
From Coetzee and Pool, 1986.



estuary is open because seawater pushes its way into the estuary during high tides. If the estuary is open during the summer, there is an increase in salinity at all three stations. This is due to high evaporation and low riverine input as well as tidal input.

Scott et al (1950) measured salinities in the estuary and found that the water in the lower reaches of the estuary became hypersaline (the highest value being 39.99 ppt) when the mouth was closed during the summer months. When the estuary is opened the salinity changes can be drastic (Day, 1950). Prior to opening, there is a large influx of fresh water, so when the estuary opens, the salinities will change quickly with the lagoon attaining a salinity similar to that of the sea. This phenomenon can be seen in Fig. 14 (a & b) in August 1984 and July 1985.

4.2.2 pH

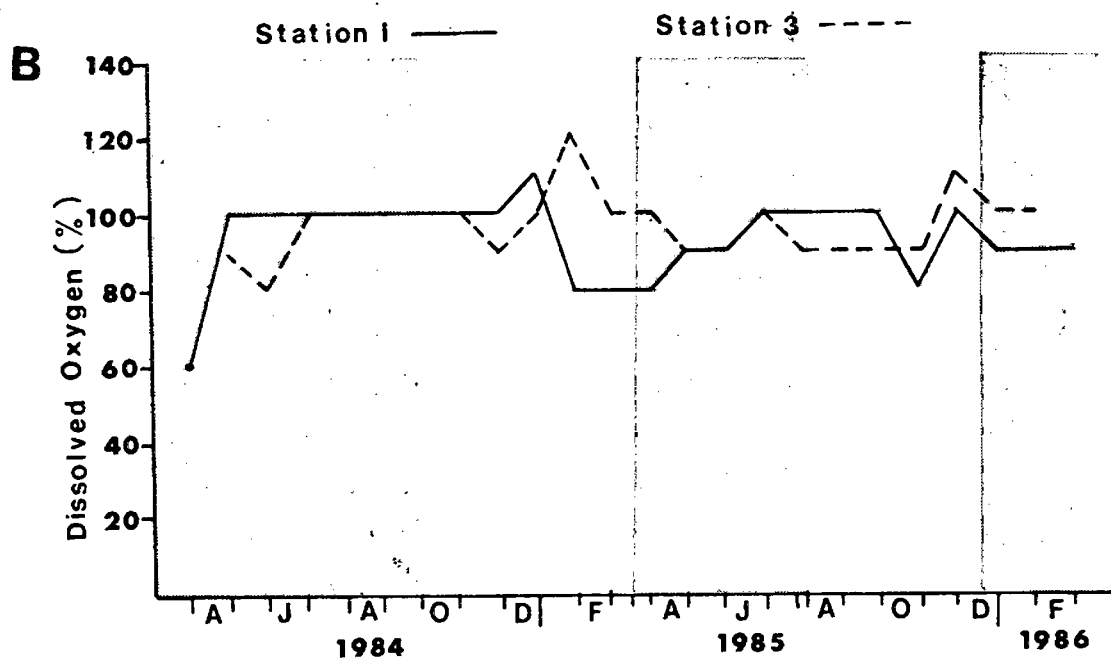
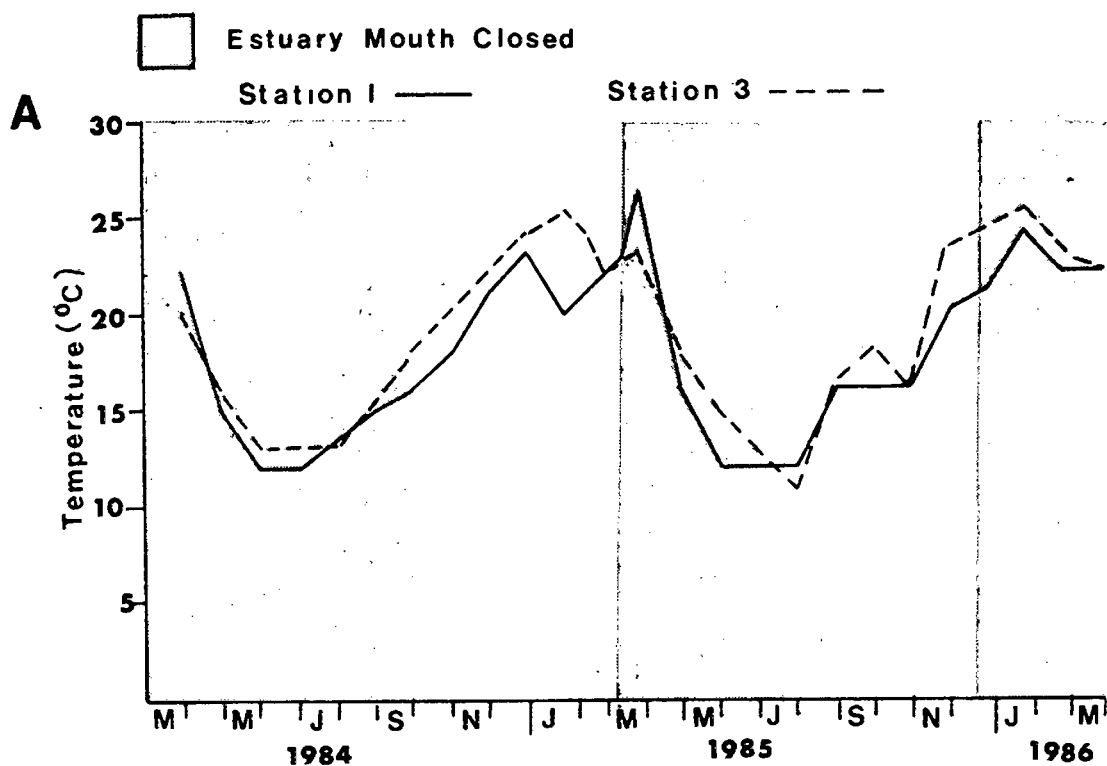
The river water flowing into the lagoon has a pH range of 6.9 - 7.0 (Scott et al., 1950), but the small streams that flow from the Kleinriviersberg are much more acidic, approximately pH 5.0. Seepage water also runs into the estuary from limestones and aeolianites to the south of the estuary (Scott et al, 1950). This seepage contains leached salts and is alkaline.

The overall pH of the estuary varies between 7.10 and 8.25 (Coetzee and Pool 1986) throughout the year, despite the acidic inflow from the streams off the Kleinriviersberg. Scott et al (1950) suggested that the seawater in the estuary has a buffering effect on the acidic water and thus the pH of the estuary remains alkaline.

In the upper reaches of the estuary at their station 3 (Fig. 13), Coetzee and Pool noted that when the river-flow was strong, the surface waters had a lower pH (7.35) than the bottom water (7.5), and this corresponds with a salt wedge, with saline water (17.5 ppt) below the fresher, less saline water (9.5 ppt).

Fig. 15 Temperature and Dissolved Oxygen in the Klein River Estuary.

From Coetzee and Pool, 1986.



4.2.3 Temperature

The temperature of the estuary fluctuates seasonally between 12°C and 28°C , Day (1981). This has been verified by my own readings in which it fluctuated between 14°C and 26.5°C . Coetzee & Pool (1986) found that the temperature fluctuates between 12°C and 25°C at their station 1, and between 11°C and 25°C at their station 3. The temperatures at stations 1 and 3 are shown in Fig. 15a. Station 2 is excluded because the values are similar to station 1.

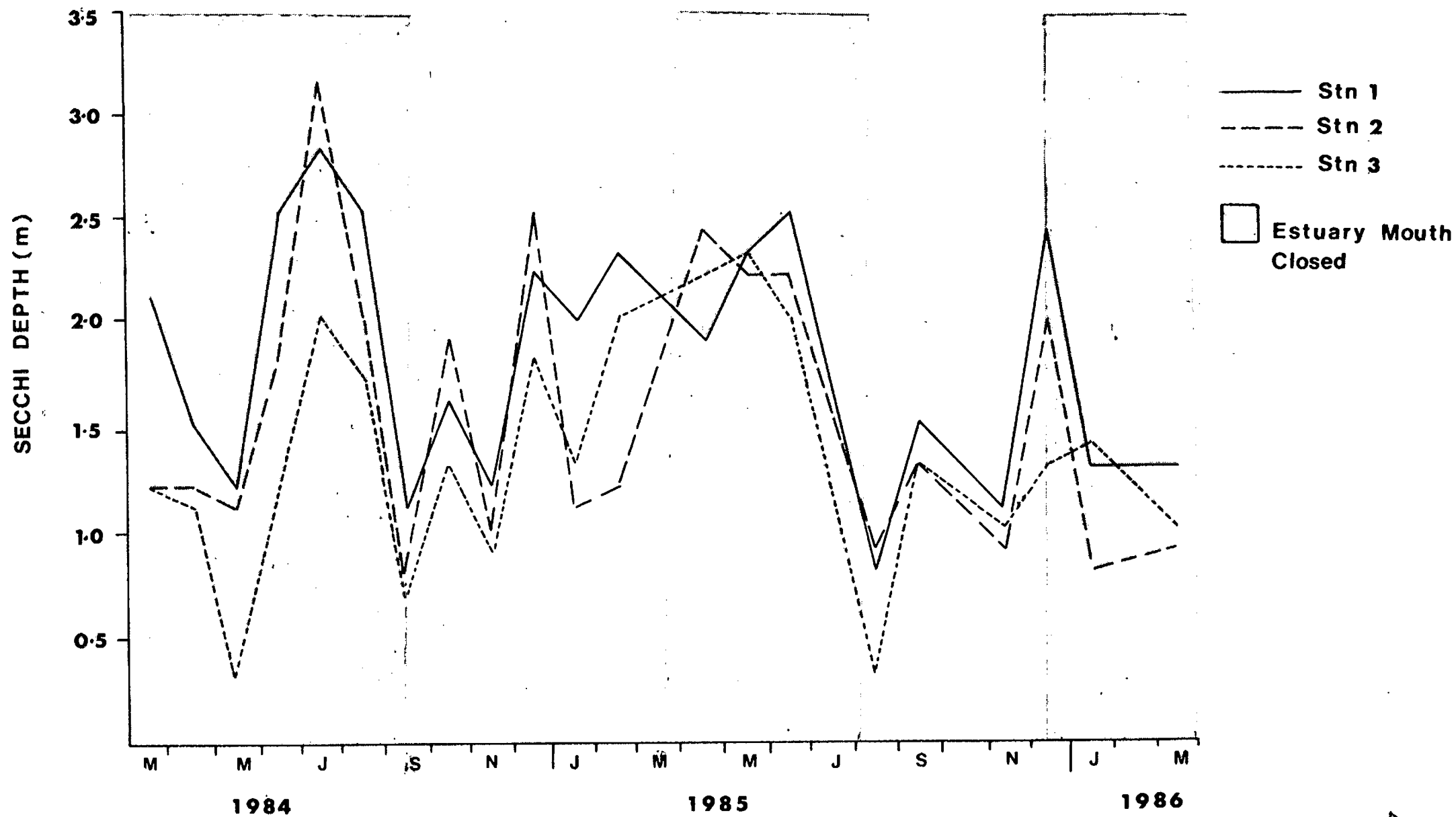
The temperature is influenced to a certain extent by the temperature of the river and the sea. The sea has a more stable temperature than most rivers (Day, 1950), so the most extreme temperature changes are usually found at the head of the estuary, a fact verified by Coetzee and Pool who found that the lowest temperatures (11°C) at the head of the estuary were associated with the inflow of cold river water. The shallow water in the lower reaches of the estuary could reach higher temperatures than the deep water, due to solar warming, but no temperature readings have been taken in this area. Periods of high or increasing temperatures are associated with periods when the mouth was open and thus the water levels were fairly low (Fig. 15a). Periods of reduced oxygen concentration occur when the temperatures are high (Fig. 15b) but even in the worst case, the water was still 60% saturated

4.2.4 Suspended Solids

The amount of suspended matter in the estuary varies as it depends on the turbulence caused by wind stress on the water. The seawater entering the estuary is clear, but the riverine water is brown in colour due to tannin staining, and contains little suspended matter unless the river is in flood, and contains silt. Sloman (1983) took sediment samples by diving and noted that the visibility can decrease from 3m to 0.2m in a few hours when there is a strong wind.

Secchi disc readings taken by Coetzee and Pool (1986) show that the turbidity can fluctuate greatly (Fig. 16), but the

Fig. 16 Turbidity in the Klein River Estuary.
From Coetzee and Pool, 1986.



general trend is that the turbidity increases (Secchi disc readings decrease) when the estuary mouth opens. This could be because the bottom sediments are stirred up by the wind when the estuary mouth is open and the estuary is shallow. Alternatively, the introduction of nutrient rich seawater could increase the phytoplankton activity, thus making the water more turbid. The maximum turbidity occurred at station 3 with a Secchi-disc reading of 0.3m. In all three stations, the bottom could be seen at times when the estuary mouth was closed.

4.2.5 Dissolved oxygen

Coetzee and Pool (1986) found that the oxygen saturation ranged from 60% to 110% at station 1 and from 80% to 120% at station 3. The open water of the lagoon is well oxygenated, probably due to the water being well mixed by prevailing winds. Fig. 15b shows the oxygen saturation at stations 1 and 3. Station 2 has been excluded since the water is 90-100% saturated all the time.

In summary, when the estuary mouth is closed, and the water levels fairly high, the salinities in the estuary are fairly low (7-12 ppt), the water temperature also appears to be fairly low (12°C) although this could be due to seasonal fluctuation as well as the depth of the water. The dissolved oxygen in the estuary remains fairly high the whole year round, fluctuating between 80% and 120%. The pH of the estuary is also fairly constant (7.1 - 8.2) and the water is usually clearer when the mouth is closed.

When the mouth is open, the salinity rises, as does the temperature and, to a lesser degree the oxygen saturation. The water in the estuary becomes more turbid when the mouth is open.

This indicates that when the water levels are high, the estuary is less saline, colder and with a higher oxygen concentration as well as being clearer.

4.3 Flora and Fauna

4.3.1 Phytoplankton

There have been no studies of the phytoplankton of the Klein River Estuary, but Koop et al (1982) surveyed the phytoplankton in the Bot River Estuary. This estuary is approximately 20 km to the west of the Klein River Estuary, and is the nearest substantial lagoon to the Klein River. The phytoplankton in the Bot River consists mainly of flagellates, but the biomass is low. The reason for a low phytoplankton biomass is thought to be wind-induced turbidity. This could be the case in the Klein River Estuary since there is wind-induced turbidity and the inflowing water is often dark brown, stained from tannin. This 'black water' rarely supports a high phytoplankton biomass, because of poor light penetration.

4.3.2 Algae

Filamentous algae are fairly prolific in the shallow water in the lower reaches of the estuary and are also found on the southern banks of the lagoon. These algae usually grow on submerged plants such as eelgrass, *Zostera capensis*, but are also free floating in some areas. The main species of filamentous algae are *Cladophora* sp, *Ectocarpus* sp and *Rhodochorton* sp. (J R Grindley, Dept. of Environmental & Geographical Science, U.C.T., pers. comm.).

Enteromorpha is sometimes found in the lower reaches of the estuary in shallow coves around the "Die Mond" campsite. Large marine algae such as the kelps, *Laminaria pallida* and *Ecklonia maxima*, are sometimes washed over the sand berm at the mouth, and can be found floating in the channels.

4.3.3 Aquatic vegetation

In the shallower water the sand or mud banks are colonised by the submerged macrophyte *Ruppia maritima* and are often fringed by *Zostera* in the deeper areas. These beds of *Zostera* and *Ruppia* are often the richest part of an estuary

because of the protection offered by the dense vegetation. As well as offering protection for free swimming animals, the mud is more stable in these areas and thus animals can construct burrows with more success. Some of the sandbanks in the mouth area are becoming colonised by *Ruppia*, but the main *Ruppia* beds are between Kettle Point and the camp site (Fig. 2). These areas rich in aquatic vegetation and algae can become locally eutrophic, especially when the water level falls and leaves algae stranded, and decomposing. The presence of eutrophic water near the campsite has been used as a reason for artificial breaching of the sand berm at the estuary mouth.

4.3.4 Semi aquatic vegetation

In the upper reaches of the estuary, there are extensive stands of the reed *Phragmites australis* (Sloman, 1983), which are particularly thick where the river enters the lagoon. These reeds are also fairly important in that they offer protection to a variety of fauna in the lagoon. However, these reeds trap sediments from the river with the result that the whole area is shallow and fairly muddy. This is also true of the Bot River Estuary which has an area of fine sediments in the upper reaches (Willis, 1985) which have been trapped by reed beds.

Salt marsh vegetation is also present in the Klein River Estuary, the main areas being to the south of the sand bar near Winter Bay and to the east of Pulpit Point. The main species in these salt marshes are *Sarcocornia* spp and *Salicornia* sp.

4.3.5 Dune vegetation

The coastal dune belt on the south banks of the estuary has been stabilised by the Directorate of Forestry (Figs. 5 & 6), and are almost entirely covered with alien vegetation such as *Acacia cyclops*, *A. longifolia* and *A. saligna*. The Directorate of Forestry is now attempting to replace these aliens on the sand dunes closest to the estuary mouth and to re-establish the natural vegetation in this area.

4.3.6 Zooplankton

There have been no recent studies of the zooplankton of the Klein River Estuary. Coetzee (1985) studied the zooplankton in the Bot River Estuary and found that the zooplankton fluctuate seasonally. However, the zooplankton numbers and biomass decreased with decreased salinity prior to the estuary opening, but the species composition remained the same. This illustrates the wide salinity tolerances of the majority of the taxa in the estuary.

Although the present species composition of the zooplankton in the Klein River Estuary is not known a thesis completed by Grindley in 1965 shows the main species to be *Pseudodiaptomus hessei*, *Phophalopthalmus terranatalis* and *Mesopodopsis slabberi*. One of the main species found in the Bot River Estuary is *P. hessei* so it could be likely that the numbers and biomass react in a similar way to the plankton in the Bot River Estuary.

4.3.7 Aquatic invertebrates

The benthic fauna is impoverished if compared with a permanently open estuary, and the species composition changes rapidly when the mouth is opened or closed, which indicates that the aquatic invertebrates do not have such a wide salinity tolerance as the zooplankton. For example, when the mouth is open, the lower reaches of the estuary are colonised by stenohaline invertebrates such as the sea urchin, *Parechinus angulosus*, which die quickly once the mouth is closed, although some species such as the bloodworm *Arenicola loveni* survive buried in the sand berm at the mouth (Day, 1981).

The fauna in the shallows of the lagoon consists mainly of isopods and amphipods such as *Melita zeylanica* and *Exosphaeroma hylecoetes*. The mud prawn *Upogebia africana* is common in most South African estuaries, but is entirely absent in the Klein River Estuary, being replaced by the sand prawn *Callinassa kraussii* which usually burrows in muddy and sandy areas (Day, 1981). This reflects the low

input of fine sediment from the catchment area. The lower reaches of the river are under minimum saline influence and it is here that the first estuarine species make their appearance, (Scott et al., 1950).

The *Ruppia* and *Zostera* beds are so dense that they offer ample protection for benthic fauna. Isopods, amphipods, chironomid larvae and small snails have all been found in these beds. The shrimp *Palaemon pacificus* is found amongst the weeds and the mussel *Arcuatula capensis* is also quite common.

4.3.8 Aquatic vertebrates

Talbot (1954) studied the biology of the white stumprhous *Rhabdosargus globiceps* (Cuvier) in the Klein River Estuary. At the same time, the fish fauna of the estuary was investigated. Most of the fish are migratory and only actually enter the estuary when the mouth is open. Some species do get trapped in the lagoon when the mouth closes, and seem able to withstand the conditions, but most of the fish leave the lagoon before the mouth closes. There is usually a high abundance of juvenile fish in an estuary as it is used as a nursery by young fish. According to Wallace et al (1983) 81 species of fish are dependent on estuaries in some way.

The most abundant fish in the estuary are the white stumprhous, *Rhabdosargus globiceps* (Cuvier), the white steenbras *Lithognathus lithognathus* (Cuvier) and the southern mullet *Liza richardsoni*. The flathead mullet *Mugil cephalus* is also fairly common and can be found as far up the river as the Stanford bridge (Scott et al., 1950).

In January 1984 the estuary was opened because there was a high fish mortality (Franks, unpublished data). The main species of fish that died was the southern mullet (*Liza richardsoni*) but it is not known what caused the fish deaths. Franks (unpublished data) says the mouth was opened to "freshen up the lagoon water", suggesting that the conditions were anoxic or in some way toxic. According to

hydrological data from the Department of Water Affairs, there was no river flow in January 1984 and only 0.021 cubic meters per second in December 1983. This shows that there was no fresh water input, a fact confirmed by the decrease in water levels after October 1983 (see Fig. 22). Conditions, therefore, would not have been too fresh for *L. richardsoni*. Branch et al. (1985) indicate that the lower lethal salinity for southern mullet is 2 - 3 ppt while the minimum salinity in which this species has been recorded is 1 ppt. (Bennett, 1985) *Liza richardsoni*, therefore, is a fairly hardy species as far as osmotic fluctuations are concerned. Branch et al. (1985) recommended that the Bot River Estuary should be opened when the salinity falls below 6 ppt, thus preventing mortality of important angling fish species.

Bennett (1985) made detailed observations before, during and after mass fish deaths in the Bot River Estuary and although 7 130 fish deaths were recorded, only 27 of them were southern mullet. The cause for mass mortality in this case is thought to be threefold, fish size (and therefore age) water temperature and duration of exposure to low salinities. Large, older fish are less tolerant of low salinities and low temperatures could reduce the ability to osmoregulate in these fish. In the case of the fish mortalities in the Bot River Estuary, the fish were all about 3 years old, the minimum temperature was 16°C and the salinity was 3 ppt for at least two weeks before deaths occurred.

Unfortunately there were no readings taken in the Klein River Estuary in January 1984 so the exact conditions are not known. It is unlikely that the salinity was low since the deaths occurred in the summer months when salinities are usually highest (Scott et al. 1950). Coetzee and Pool (1986) report 4 ppt as being the minimum salinity recorded during their survey between March 1984 and March 1986.

Prof J Grindley collected some of the dead *L. richardsoni* and found that the average size was 246-249mm. The estuary was open from July 1st to October 1st 1983. Since the fish

were approximately 3 years old (Bennett pers. comm.) it is unlikely that the fish that died were spawned when the estuary was open in July 1983. Previous openings occurred in August 1981 to April 1982 and in September 1982. Bennett et al. (1985) reported that peak spawning activity is during the early summer and thus it is possible that juvenile fish may have entered the Klein River Estuary between August 1981 and April 1982. Another possibility is that adult fish entered the estuary between July 1st and October 1st 1983, and were trapped when the mouth closed.

It is unlikely that the cause of death of the southern mullet in this incident is the same as that in the Bot River Estuary, since only one species and one size was affected (Grindley pers. comm.). The fact that the fish were all one size is not surprising since all the fish probably entered the estuary at the same time. The fish trapped in the estuary when it closed are thus all of the same age. The fact that the fish were one species is of more significance. There are several theories as to why the fish died (Dr D Coetzee, CDNEC, Jonkershoek pers. comm.), ranging from stress due to overcrowding and the presence of many power boats, to a sharp decline in the availability of food. One possible explanation is the presence of oxygen depleted bottom water, in a stratified water column. (H Waldron, Department of Oceanography, UCT, pers. comm.)

If stratification occurs, the bottom water may become anoxic, thus denying the sediments to the fish. Being detritivores, they could have starved or been sufficiently weakened to have succumbed to disease. However, the fish were in good condition (Grindley, pers. comm.), and not likely to have been suffering from disease. The presence of oxygen depleted water is supported by the fact that Coetzee and Pool measured their lowest oxygen saturation values (60% at station one) when they first started their survey in March 1984, two months after the fish deaths. However, the fish deaths occurred in January and the wind had been fairly strong for the week prior to the deaths, suggesting that the water should have been well mixed.

There does not seem to be any clear reason for the death of the *L. richardsoni* but it is an unusual phenomenon that has not occurred before or since January 1984.

Many other fish species occur in this estuary when the mouth is open, and there are three estuarine species that are common: the whitebaits *Gilchristella aestuarius* and *Atherina breviceps*, and the small goby *Psammogobius knysnaensis*

There has been a marked decrease in fish catches over the past few years in the estuary and the fishing is reputed to be not as good as it was in the 1940s but the memories of anglers are notoriously unreliable. Some anglers blame the poor fishing on the position of the estuary mouth but others believe it is linked with the fact that the sediments in the lower reaches of the estuary are building up. It is likely, however, that the decrease in fish is due to the increase in anglers in the area.

In summary, it would appear that the fauna and flora in the estuary benefit from high water levels, but it is only natural that the estuary experiences low water levels when the sand berm is breached. However, the level should be allowed to rise as high as possible since the biota benefits from these conditions. The mass mortality of *L. richardsoni* occurred in unusual circumstances and has not occurred before or since January 1984. A single incident should not provide the basis for premature opening of the mouth.

CHAPTER 5

5. PROBLEMS RELATED TO WATER LEVELS

5.1 Flooding of low lying land

There are two areas in which high water levels are a problem; along the shores of the estuary, and along the banks of the Klein River itself.

Low lying land on the estuary banks

There are some properties along the northern banks of the lagoon which are threatened by high water levels. The Scout Camp, which is almost at the mouth of the estuary, is not flooded but the Municipal "Die Mond" caravan and campsite, having a low lying area on the shores of the lagoon can be flooded. This results in several individual sites and a road becoming covered by water.

Maanskynbaai, east of Kettle Point, is also flooded occasionally, therefore property owners in Maanskynbaai only have permission to build semi-permanent, wooden structures and boathouses. Unfortunately, some of the owners have nevertheless built brick structures in areas liable to flooding.

The Yacht Club buildings themselves are not in any danger from flooding, but their jetties will be submerged when the water level is high. Should the water level be likely to cover the jetties frequently, they would have to be raised or marked with poles as they are a boating hazard when concealed by water.

In the upper reaches of the estuary, there are marshy areas which are partially flooded in times of high water levels. The actual area of flooding is minimal and there have been few complaints to Nature Conservation Officers by the farmers (Visagie pers. comm.).

On the south shore of the estuary there is a road to the "Le Bos" forestry station. This road runs close to the river

and is often flooded. This section of the road could be diverted onto a higher ridge and the flooding problem eliminated.

Low lying land on the river banks

There are two main problems linked to high water levels in the Klein River. These are the flooding of farmland and the flooding of new developments in Stanford.

At the inception of this study it was considered that one of the main factors concerning high water levels and the opening of the Klein River Estuary was the flooding of farmland. The consequent loss of crops and income was believed to be a major problem. The areas concerned are upstream of the estuary on the stretch of river between the lagoon and Stanford. One possibility considered was that such flooded lands could be purchased by the authorities responsible for managing the estuary.

The problem of flooding of agricultural land does not seem to be as significant as was first supposed. If the water levels in the lagoon are high, the marshy area at the head of the lagoon, where the river enters, is flooded. This is an area of mud banks and reeds (mainly *Phragmites australis*) as shown in Fig 17. Another area that can be flooded is on the southern banks of the river, next to the marshy area mentioned above (Fig 18). The high water mark can be seen clearly on the orthophoto map (Sheet 3419 AD 19 Springfontein), as can some of the fields adjacent to the river. These fields are actually on the floodplain (Heydorn & Tinley, 1980). The area flooded on the southern banks is approximately 0.18 km^2 or 1.8 hectares. The crops grown in these fields are mainly cash crops such as potatoes, pumpkins and onions. The average annual income from these fields is approximately R300/ha. The estimated value of this land is R3 600/ha (van Rooyen, pers. comm.)

The transition zone between the water and the land is a sensitive area and plays a part in preventing erosion, water pollution and damage from floods (Clark, Banta & Zinn, 1980). In order to preserve this edge zone, a buffer strip

Fig. 17 Water levels in 1973 and 1976 in the Klein River Estuary.

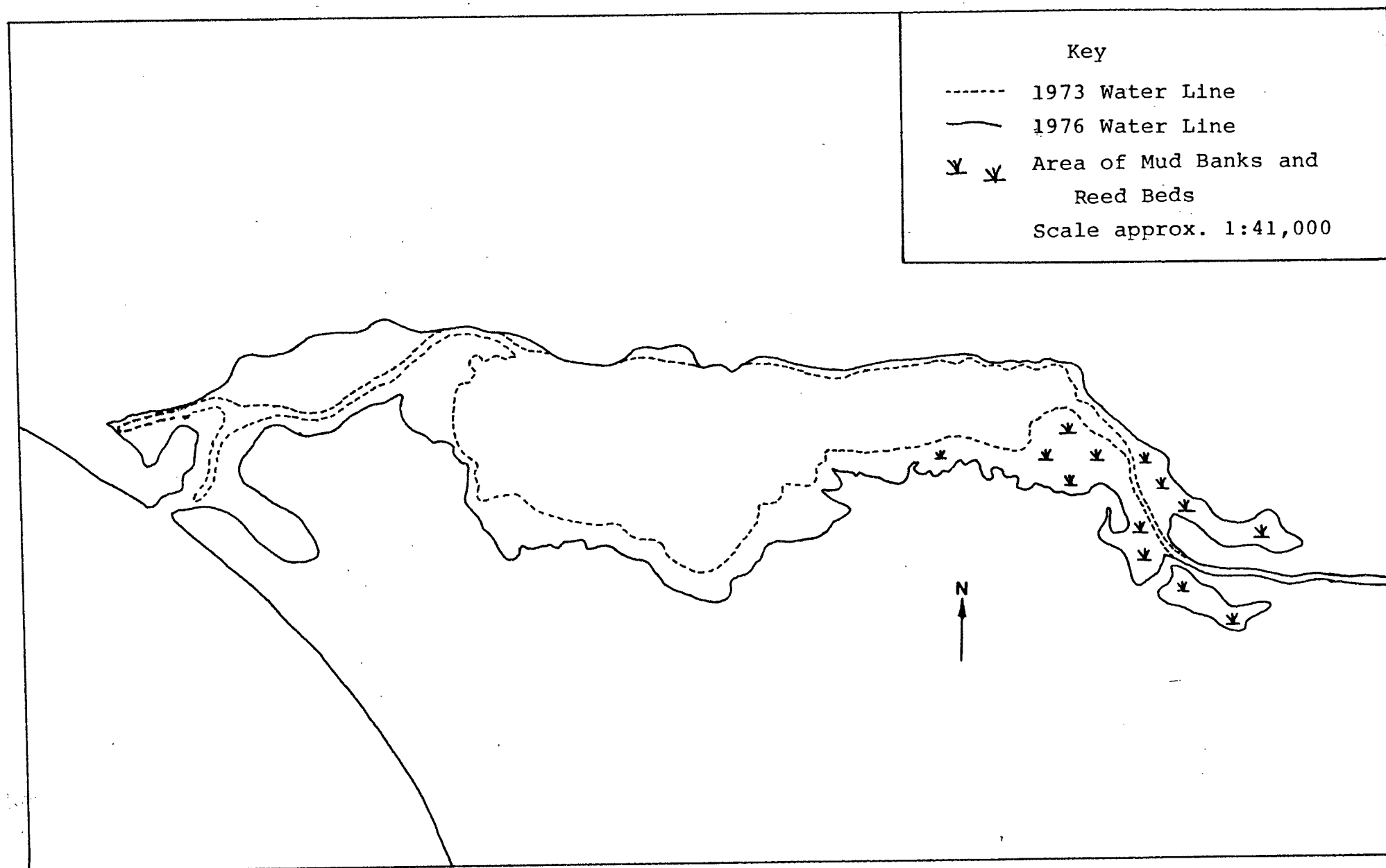
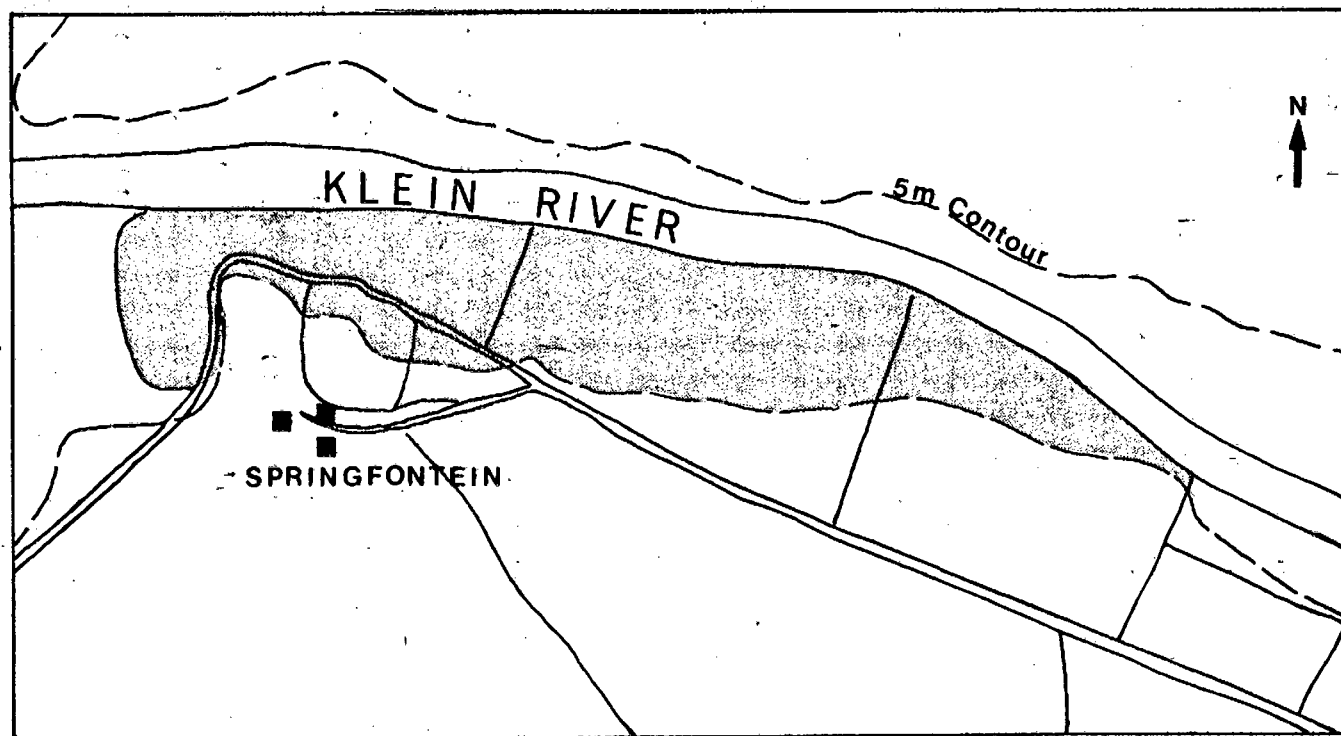


Fig. 18 Flooded lands on the Klein River.

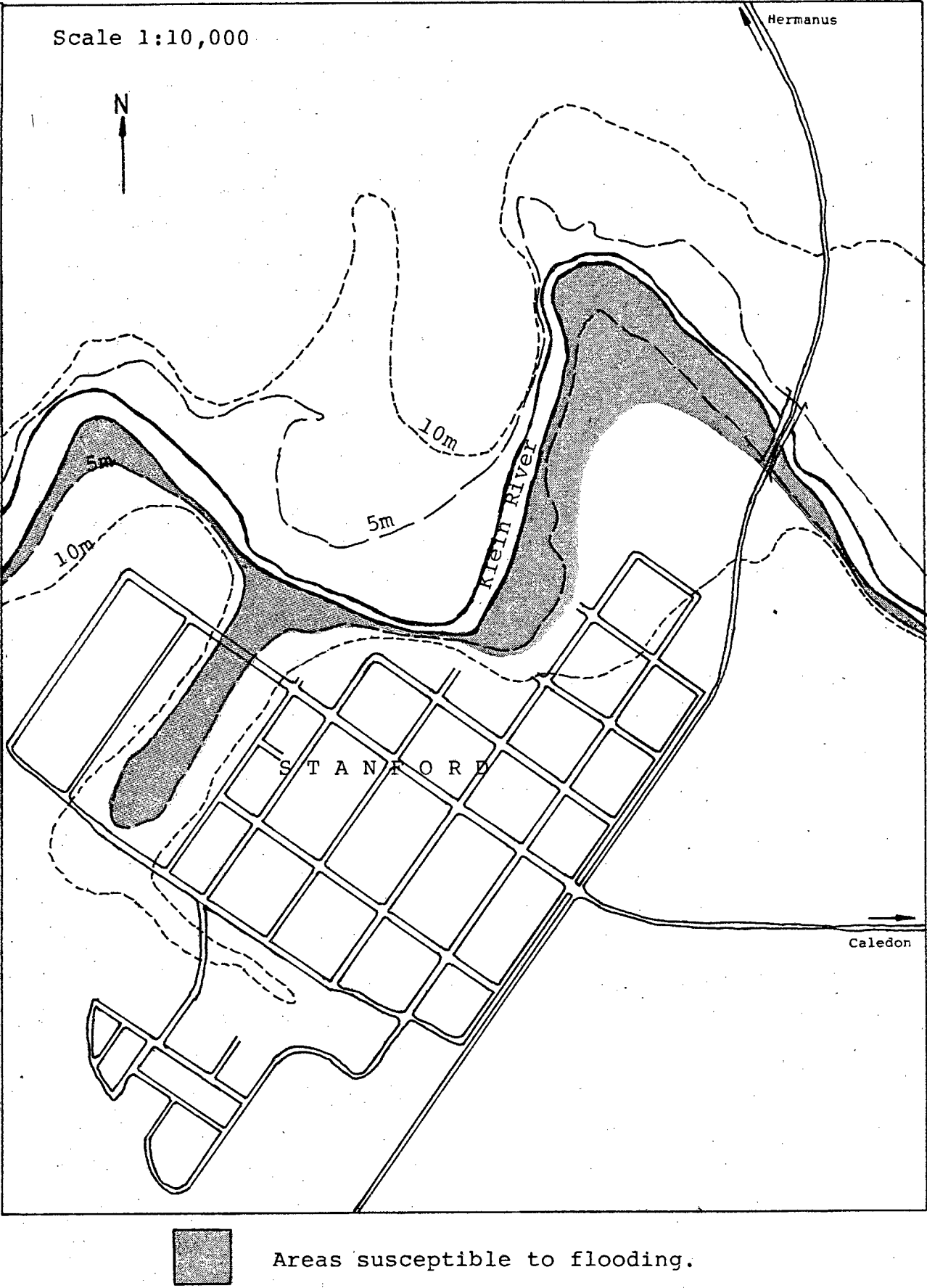
From Orthophoto sheet 3419 AD Springfontein.



 FIELDS SUSCEPTIBLE TO FLOODING

Scale 1:10,000

Fig. 19 Map of Stanford showing low lying areas susceptible to flooding.



- Development adjacent to an estuary should not be permitted below the 50 year or, where possible, the 100 year floodline.
- Estuary mouths may only be opened artificially at predetermined water levels after consultation with the Department.

These guidelines should be followed and any proposed low-lying developments should not be passed by planning authorities.

There are several factors contributing to the flooding of low lying land. If the estuary mouth is closed, lagoon levels rise, and the estuary can not easily absorb the large fluvial influx resulting from a period of high rainfall. Consequently the river water level rises and low lying land is flooded.

The Klein and Hartebees rivers are both heavily infested by alien vegetation such as *A. longifolia*, *A. saligna*, *A. mearnsii*, *Albizia lophantha* and *Eucalyptus lehmanni* which are actually growing in the river and on the banks. The stretches of river free of alien vegetation are frequently occupied by Palmiet (*Prionium serratum*) which is growing from bank to bank. Palmiet is an indigenous plant and often prevents bank erosion, but in this case, can act as a dam to any debris floating downstream. If the river was cleared of alien vegetation, it would flow faster and more freely, there would be less silt deposition and it would be less susceptible to flooding. It is expensive to clear such a well established stand of alien vegetation and if one farmer does it, his land is liable to have even worse flooding if the river downstream is still blocked by plants. The alien vegetation has blocked the river to such an extent that water levels in the river become disproportionately high compared with the incoming rainfall. It is thought that the presence of alien vegetation in the river combined with a high water level in the lagoon and a period of high rainfall in the catchment area would cause serious flooding up stream from Stanford. Below Stanford the river is relatively clear of alien vegetation. High estuary water levels combined

with a period of high rainfall would be the cause of flooding in this case.

The partially blocked river might even be forced to change its course into one of the low lying areas on the northern banks and thus flood the main road between Stanford and Hermanus at Stanford.

In conclusion, the problem of flooded fields and loss of crops is not as significant as was first suggested, a fact confirmed by local landowners and residents. Proposed new developments in Stanford, however, face a real threat of flooding. Such developments should not be permitted on low lying land. If houses are built on land that is known to have been flooded, they should be of such a nature that they can withstand flooding. For example, built on elevated pilings or post supports. It is important that the threat of flooding is not used to justify the artificial opening of the estuary mouth.

5.2 Flora and fauna

The most important components of the flora and fauna are described in Chapter 3. The groups of animals and plants affected most by water levels are those in areas that will be exposed by low water levels. The fish in the estuary will be more affected by the opening of the estuary mouth than by water level variations in the lagoon itself.

Under natural conditions, the water would rise to a high level before the sand berm is breached. Breaching of the berm causes rapid draw down, exposing sand and mud banks, and areas that are colonised by *Ruppia maritima*, *Zostera capensis* and various green algae. These areas are also fairly rich in fauna since they offer a protected habitat. The fauna and flora will be exposed to predation, exploitation and desiccation. However, when the water level rises again (following closure of the estuary mouth) these areas should become re-colonised rapidly.

In the Bot River Estuary, 20 km west of the Klein River Estuary, breaching of the sand berm causes large disruptions

to the system. The *Ruppia* in the estuary is virtually eliminated, and according to Branch et al. (1985), the recovery of this weed is slow, recovering by only 40%, 14 months after the mouth was opened.

The Klein River Estuary differs from the Bot River Estuary in that the water level changes are not so drastic. The water level in the Bot can change by 240cm in 24 hours (Branch et al. 1985). The largest drop in water level in the Klein River Estuary is 61.1 cm in 7.5 hours on September 5th, 1982.

Another effect of the decrease in water level is the potential decrease in the area shallow enough for the growth of aquatic vegetation. If the water level in the Klein River Estuary dropped by approximately 150cm to sea level, the change in area would be approximately 5.68 km² (see Appendix 2 which contains calculations of area and volume at different water levels). This would result in a large decrease in shallow water, and hence in the estuary's primary productivity. Bally et al. (1985) showed that if the water level of the Bot River Estuary is between 0.5 m and 1.5 m above MSL, the area available to macrophytic growth is 29% less than when the estuary is full (above 2.0 m above MSL).

The speed at which the water level rises can also be important to the flora and fauna of an estuary (Branch et al. 1985). As the level increases, new areas become inundated by water which gradually becomes deeper, allowing for the progressive colonisation by diatoms, algae and macrophytes. Simultaneously the water at the other end of the shallow zone becomes too deep to support significant primary production (Bally et al. 1985). If the water level rises too rapidly, some macrophytes will not be able to grow quickly enough to remain in the well-lit zones of deep areas. These areas could consequently remain uncolonised.

Changes in the size of the macrophyte beds affect the invertebrates, fish and birds in the estuary, although the fish are more dependent on the time during which the mouth

is open. Several species of fish, for example the white steenbras *Lithognathus lithognathus* and the flathead mullet *Mugil cephalus*, depend on estuaries as nursery grounds (Bennett et al., 1979) and could face extinction if denied access to estuaries (Wallace et al., 1984). Most species important to sport fishermen are marine migrants and periodic breaching of the sand berm is important in maintaining these fish populations in the estuary. However, De Decker and Bennett (1985) showed that the southern mullet *Liza richardsoni* actually benefited from being trapped in an estuary for 4 years. The trapped fish had eight times more fat than their marine counterparts and were in a generally better condition. The reason for this is thought to be that the fish do not expend energy through spawning, and the conditions of high food availability and low predation are beneficial resulting in rapid growth and good condition. The nature of the bathymetry of the Klein River Estuary, means that water level makes a large difference to the area and volume of water. If the water level is high, the area is approximately 11.28 km^2 and the volume is approximately $24.41 \times 10^6 \text{ m}^3$. Whereas at low water levels the area is 4.27 km^2 and the volume is $4.08 \times 10^6 \text{ m}^3$. During low water periods therefore, the fish population would be confined to the deep water in the centre of the lagoon and channels. Since the water level is low when the mouth is open or has just closed, the majority of the fish would be juveniles and probably prefer the shallower water. Once the mouth is closed, the water levels rise and the area of shallow water, and of macrophytes increases and the conditions become more beneficial to fish recruits. Periodic low levels are inevitable after breaching of the sand berm and have to be endured otherwise there would be no fish recruitment.

If the Klein River Estuary is to be opened artificially, it is important that consideration be given to the timing of the opening with respect to fish recruitment. Bennett et al. (1985) suggest that the best time for opening an estuary is during the summer when recruitment is strongest. Day (1981) shows that peak spawning activity occurs in spring

and early summer (August to November) hence most recruits are available in the summer. However, summer is not the best time to open the estuary since water levels tend to be lower and the flushing effect of the out-going water reduced, also fluvial input is low so the system will be slow to refill just when recreation demand is highest. Bennett et al. (1985) conclude that October or November are probably the best months for artificial breaching of an estuary mouth.

As far as the condition of fish in the estuary are concerned, it seems that the longer the mouth is closed and the higher the water level, the better, unless the water becomes very fresh and fish die. If the Klein River Estuary was left to breach the sand berm at the mouth naturally, it would probably breach it annually, since the water levels rise high enough to top the sand berm in 12 - 18 months.

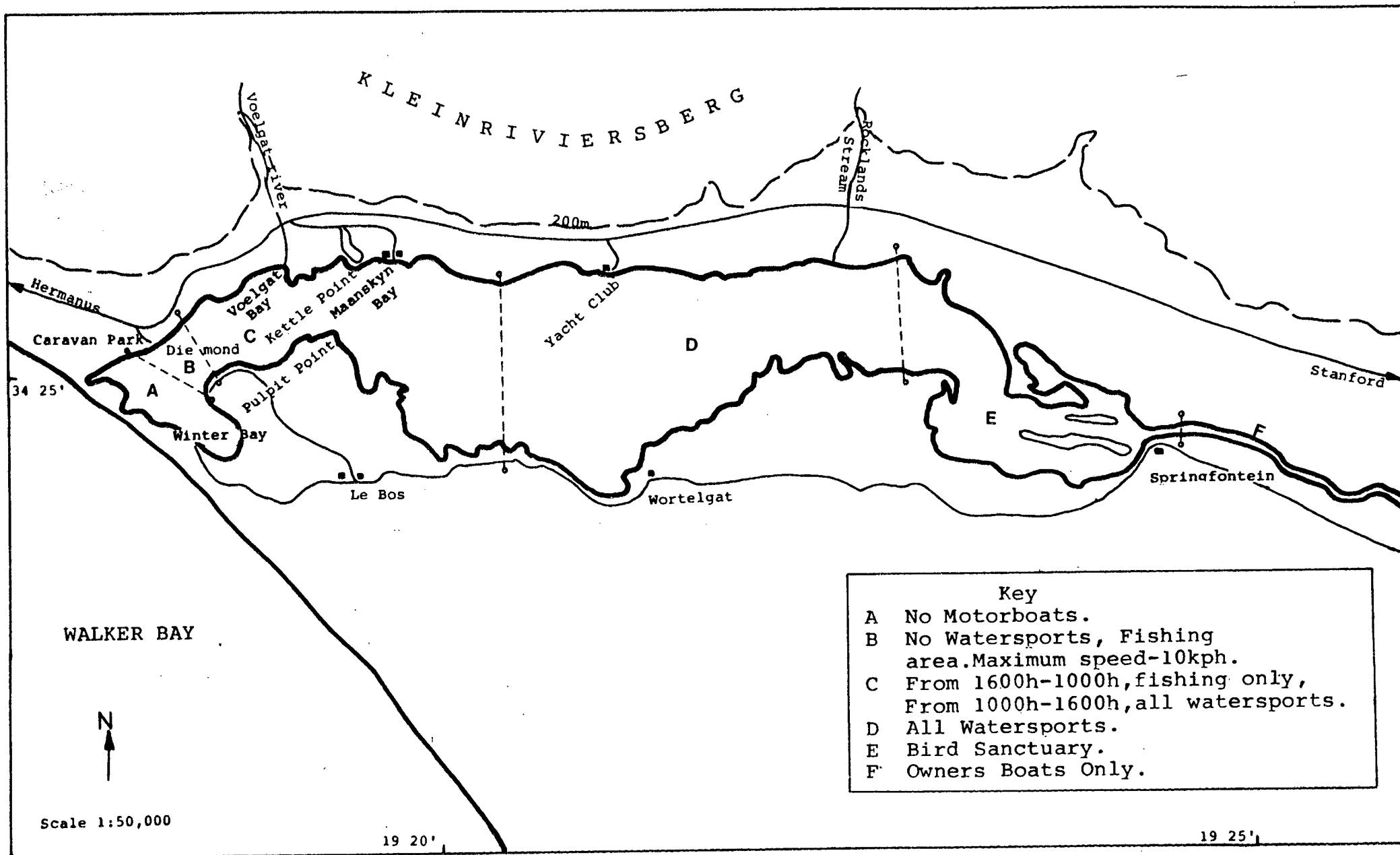
In conclusion, although rapid changes in water level can be detrimental, the flora and fauna recover from changes in water level fairly rapidly, since periods of low water levels do not persist for too long. Organisms in South African estuaries have evolved with the "boom-or-bust" regime and thus can respond fairly rapidly to such rapid, extreme changes. The life in the estuary will benefit from high water levels and the fish fauna benefit if the mouth is closed for a long time.

5.3 Recreation

The main forms of recreation in the Klein River Estuary are fishing, sailing, board sailing and water skiing. The lagoon is divided into six areas, each having a different recreational status. The divisions are shown in Fig. 20, each area is demarcated by two beacons placed by the Department of Nature Conservation. The areas and their restrictions are as follows:

- A) No motorboats allowed.
- B) No watersports, area reserved for fishing only with a maximum speed for boats being 10 kph.

Fig. 20 Division of the Klein River Estuary for Recreation.



- C) From 16h00 to 10h00 (i.e. overnight) the area is reserved for fishing but from 10h00 to 16h00 (daylight hours) all watersports are allowed.
- D) All watersports are allowed, but the authorities can stop motorboats if a sailing regatta is in progress.
- E) Bird sanctuary, only boats with official permits can enter this area.
- F) Only owners of riverside property are allowed to use boats up the river.

This division of the estuary ensures that people involved in their own recreational activities do not disturb others. This system has become difficult to enforce and a new zonation was introduced in 1986. The new zonation has fewer divisions, opening the main part of the estuary to all types of recreation at all times.

All the recreation activities on the lagoon benefit from higher water levels as the surface area of the estuary differs significantly between high and very low levels (Appendix 2). Fig. 14 shows the water level in 1973 when there was so little rain that the mouth did not open, and in 1976 just after the sand berm had been breached and the mouth was open. If the level is low, the sand and mud banks in the lower reaches of the estuary are exposed. The same happens in the upper reaches of the estuary where the river enters the lagoon. When the level is high, these expanses of sand and mud are covered by water which is aesthetically attractive as well as providing a larger water surface area for recreation.

The Klein River Estuary has been a well known fishing spot for many years, and this sport is still very popular in the estuary. It has already been stated that the fish population benefits from higher water levels and from the estuary mouth being closed for longer, therefore letting the estuary open naturally or at least allowing the water to rise to a high level would seem to be the best option.

Most of the recreation on the Klein River Estuary involves the use of motor or sailing boats. The public access to the estuary for purposes of launching boats is limited. If the

water levels are low, the only place available for launching boats is at the campsite. This is yet another good reason for maintaining a high water level in the system.

The sand berm across the mouth of the estuary is also used as a recreation area by people with beach-buggies or four wheel drive vehicles. During the summer when the estuary mouth is usually closed, the whole sand berm is utilized by vehicles, either launching boats and sailboards, or just driving in the sand. The sand has become compacted as a result of extensive use by vehicles, and this could result in a decrease of sand berm organisms.

Another recreational activity on the lagoon is power boating. When the water level is low, the surface area of the lagoon is decreased, especially in the lower reaches of the estuary, where the water is confined to the channels in the mouth area. Fast boats have larger wakes than the slow boats, and can cause bank erosion and disturb anglers. This effect is reduced at higher water levels, since the wake can spread over a larger water surface area rather than be confined to the channels. Speed boat engines might actually aid in decreasing the sediment in the mouth area because they can stir the sediment into suspension. If the mouth is open, the suspended sediments can then be washed out of the estuary into the sea (van Heerden, pers. comm.), but this effect is of minor significance. Boat safety precautions are of major importance and so there should be no speeding in the channel.

5.4 Estuary mouth dynamics

The mouth of the Klein River Estuary has been opened artificially for many years. Written records by Franks (unpublished data, Appendix 1) show that the mouth has been opened artificially since at least 1948, but Tredgold (1980) mentions farmers and fishermen opening the mouth with shovels as far back as the 1890s. The reasons for opening the mouth vary from the drainage of farmland in the upper reaches of the estuary, to the improvement of angling in the lagoon (Coetzee & Pool, 1986). Unfortunately, it is thought

that the artificial openings of the estuary are causing an increase of sediments in the estuary mouth (Heydorn and Tinley 1980, Grindley and van Heerden, pers. comm.). A comparison of the state of the estuary mouth in 1938 with that in 1981 is presented in Fig. 21. The sediments in the mouth area to the south of the line A-B were present in both years. The channel to the north of the line A-B was in the same place in both years, but was wider in 1938 although the water level was probably lower in this year. The shaded area in this diagram shows the unvegetated sand present in 1981 but not in 1938 ie the sand that has entered the estuary during this 40-year period. The rest of the area is covered by weeds and would be under water during periods of high water levels. This diagram shows that there has been an increase in sediment in the mouth area since 1938, but it is difficult to quantify this increase.

Ever since the estuary has been opened artificially, there has been a controversy about the position of the estuary mouth which has been opened in three positions in the past. The three positions are shown in Fig. 22, which is a profile of the sand berm in April 1985. The positions are known as the eastern, middle and western positions. The estuary had been opened at the west side of the sand berm in October 1984, and had closed in March 1985. It had been opened at the west side on four other occasions (September, 1982; July, 1983; January, 1984 and October, 1984), and it can be seen that this is now the lowest area of the sand berm. Altogether, since 1948, the estuary has been opened seventeen times at the eastern side, eleven in the middle and nine at the western side.

Fig. 23 shows the estuary mouth in three different mouth positions. From this diagram the main channels in the sediments can be seen. The main channels remain in the same place regardless of the mouth position. In recent years, the eastern channel has also become well established and now is present regardless of the position of the mouth.

Fig. 21 Sediments in the estuary mouth.

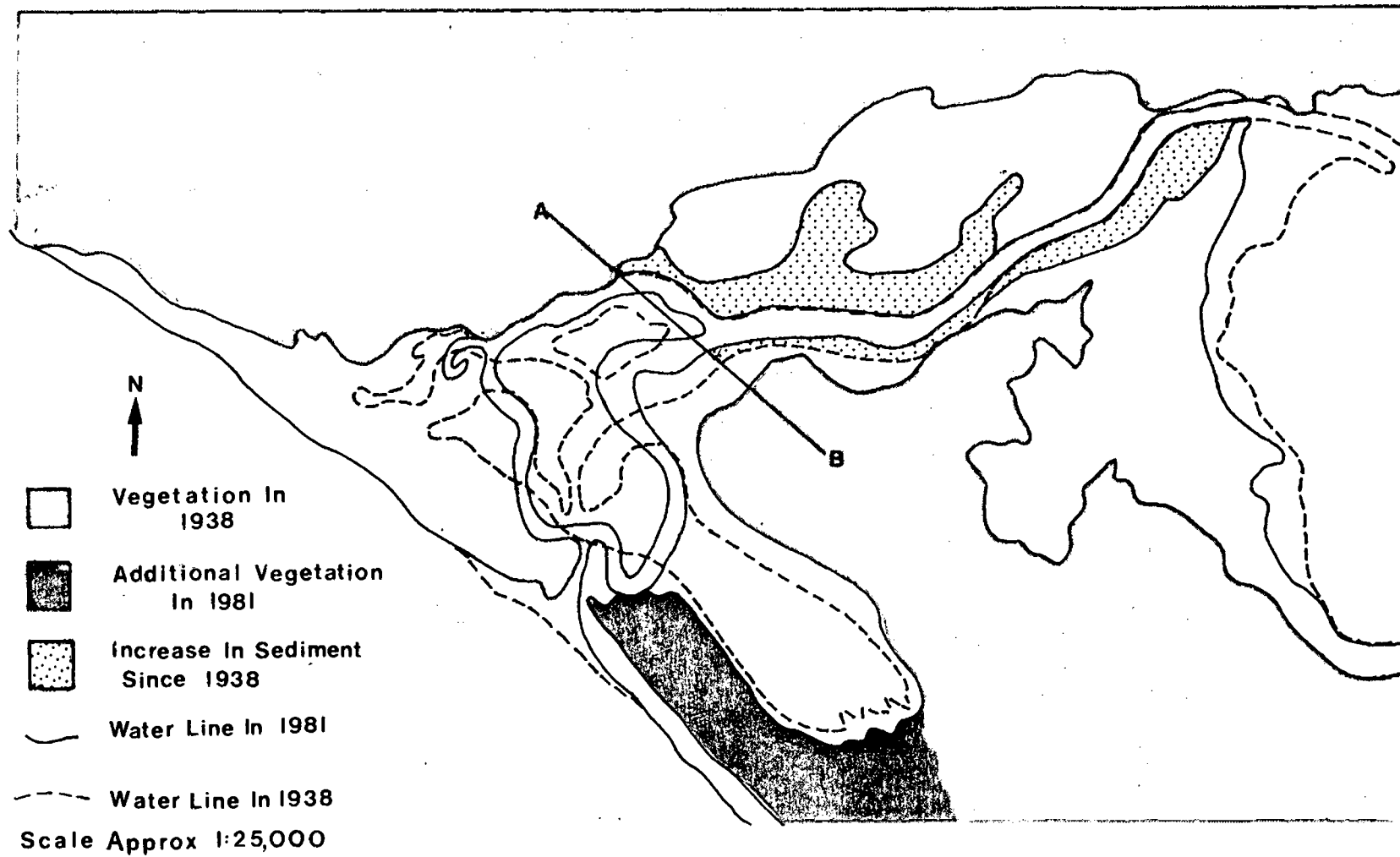


Fig. 22 Profile of the sandbar at the mouth of the estuary.

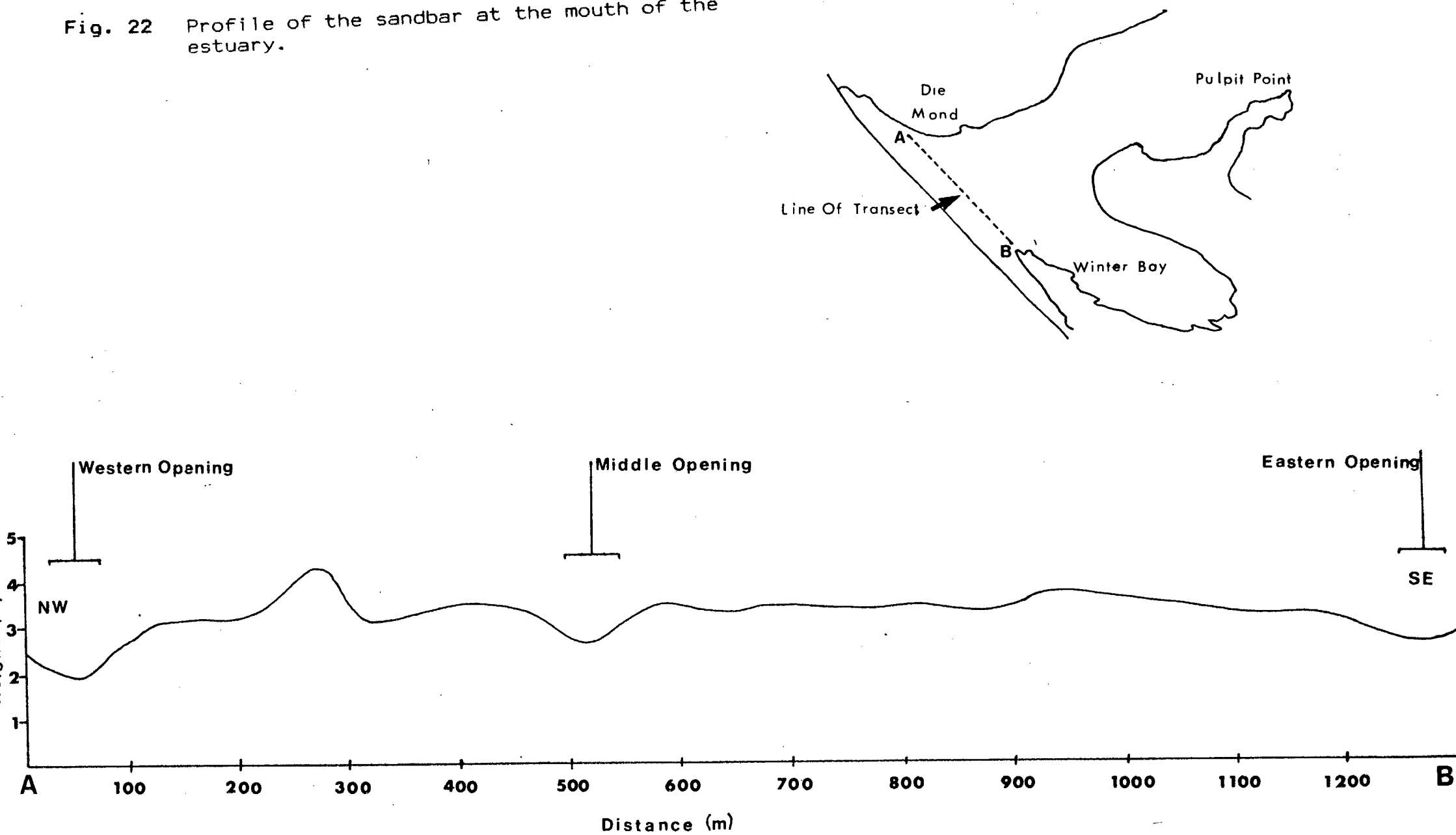





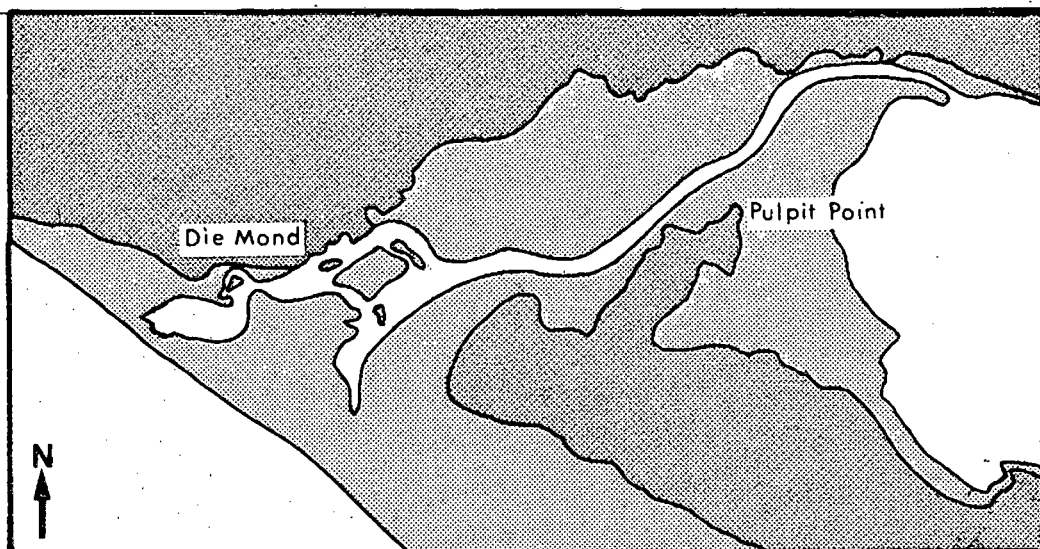
Fig. 23 The three breaching positions.

From aerial photographs, Dir. Surveys, Mowbray

1938 WESTERN OPENING

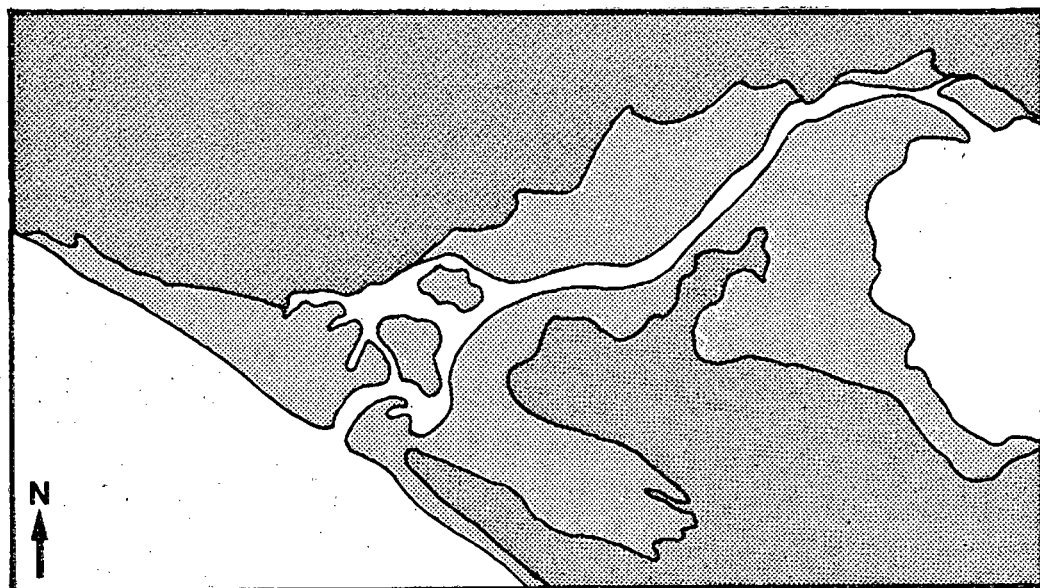
KEY

-  Sand
-  Vegetation
-  Water



approx 1 km

1961 MIDDLE OPENING



1981 EASTERN OPENING

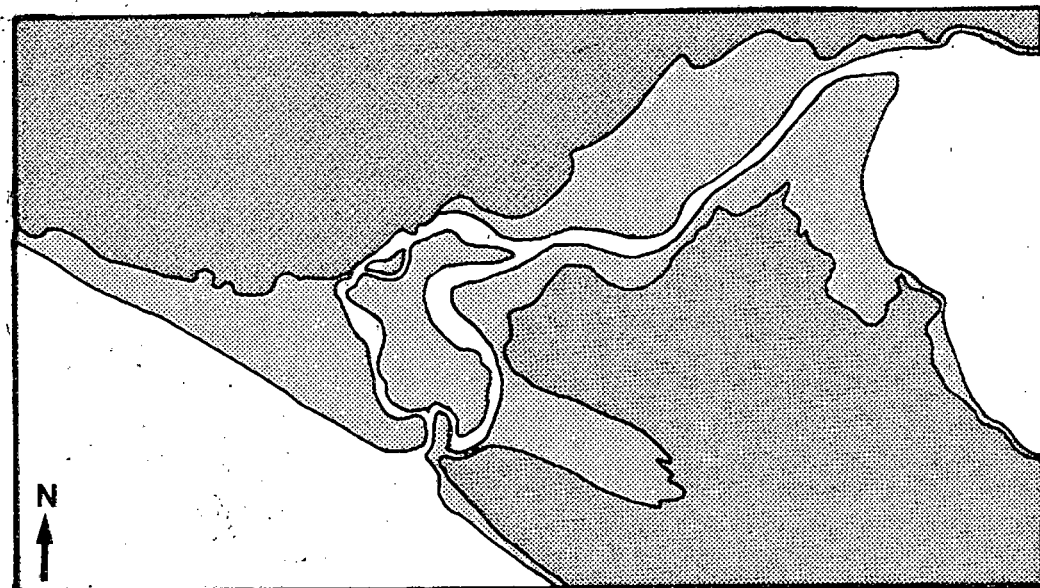


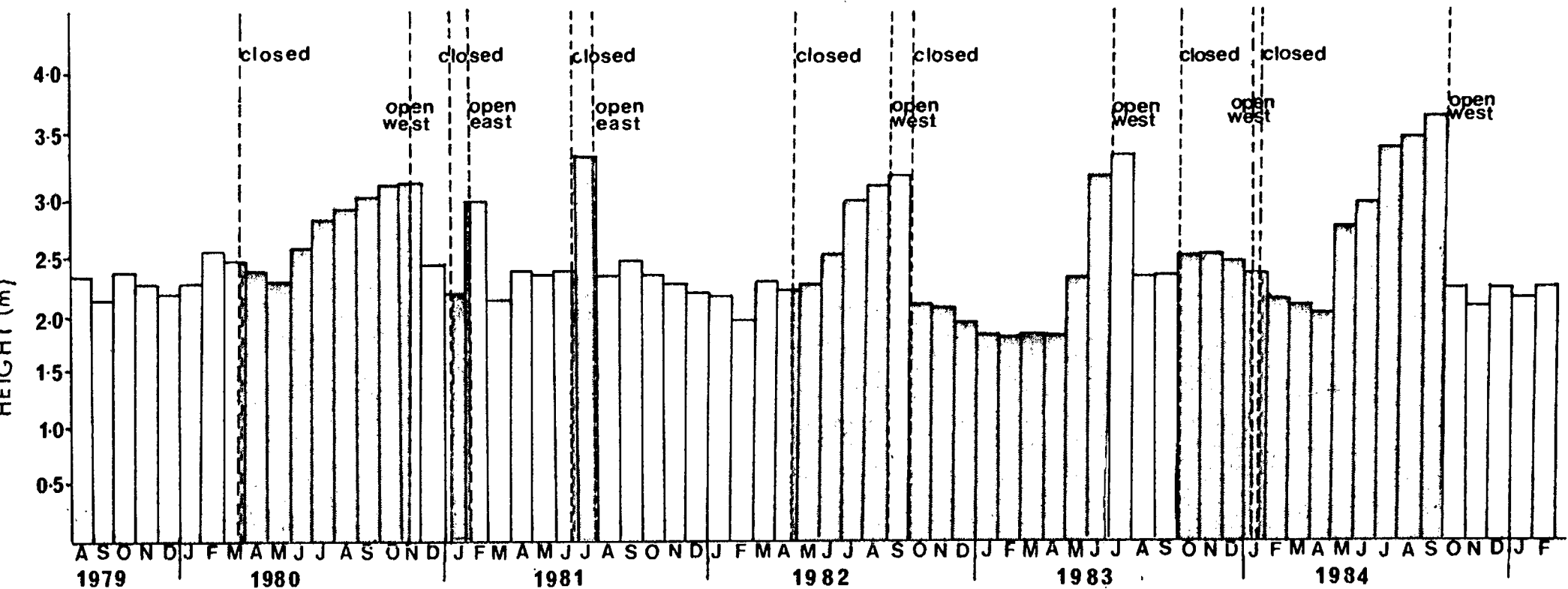
Fig. 24 shows the average monthly water levels and the time and duration of the openings since August, 1979. It can be seen from this that when the mouth is at the eastern side, the estuary stays open longer than when it is open on the western side.

If the mouth is opened at the eastern side, it tends to stay open longer, possibly allowing more fish to enter the estuary. No measurements of sediment movement during a mouth opening have been recorded, thus no conclusions can be drawn about the amount of sediment entering the estuary at each mouth position. It is possible, however, that the longer the mouth remains open, the more sediment can be transported into the estuary with each high tide. If this is so, then the sediment accumulation in the mouth would be less rapid if the mouth were to be opened at the western end of the sand berm. This position is more satisfactory as far as recreation is concerned because the water would then flow along the northern banks of the estuary, in front of the campsite. Launching of boats would be easier and the mouth area would be more attractive since the water in front of the campsite would be flowing and not stagnant. The western position would also prevent off road vehicles (ORVs) from gaining access to the beach

On the other hand, if the mouth is open on the eastern side of the estuary, the sediments that are washed out in the initial outrush of water are likely to be transported away from the sand berm during the summer when the winds are stronger. This is because the long-shore drift is from the west to the east during a south easterly wind but from the east to west during a north westerly wind. If the mouth is at the western end of the sand berm, the sediments could be returned to the estuary by overwash as they are transported along the coast (van Heerden, pers. comm.).

Sand is being removed from the barrier by contractors who use it for building. At the moment, the sand is being removed from the western side of the barrier and is thus making the barrier lower at this end. This is encouraging western mouth openings, even when the estuary breaches

Fig. 24 Average monthly water levels, mouth openings and the length of time the mouth stays open in the Klein River Estuary.



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naturally. It is impossible to say where the most natural mouth position should be, until an extensive survey is undertaken in this area. However, it would probably be advisable for contractors to mine sand from the highest part of the sand berm (in the middle) rather than the lowest, so the sand berm breaches naturally without encouragement on the western side.

ORV movement on the sand berm will be restricted if the mouth is opened in the middle or western positions, but this would only be for a short period of time, when the channel is too deep to cross. ORVs should not be allowed on the sand berm since they can have a deleterious effect on the burrowing organisms in the sand and are a danger to people using the beach.

Although the estuary has been opened in the middle eleven times, it has not been opened in this position since 1977. In some aerial photographs (1961, 1979, December 1981), the beach is slightly wider in the centre of the sand berm. Dr van Heerden (pers. comm.) suggests the reason for this could be the result of the shape of the bay, the bathymetry and the angle of approach and size of ocean swells in Walker Bay. It is possible that if the system is left to breach the sand berm naturally, either the eastern or western positions will be preferred to the middle of the sand berm which could increase in height in the centre due to the nature of the sediment movement in Walker Bay. A detailed sedimentological survey would need to be undertaken to confirm these theories.

The sediment in the mouth of the estuary has two main sources; marine, and from bank erosion (van Heerden, pers. comm.). Another minor source of sediment is wind blown sand from the dunes and beaches.

Of these two sources the main source is marine sediment which comes from long shore drift, overwash and from the sea penetrating into the estuary when the mouth is open (van Heerden, 1985). The fluvial sediment is probably a minor source, most of it being deposited near the head of the estuary as is sediment from bank erosion but the exact

amount of fluvial sediment in the main body of the lagoon is not known. The wind blown sediment is also a fairly minor source because the sand dunes to the south of the mouth are vegetated. In spite of this vegetation, some sand is still blown into the estuary from the dunes, and some sand is also blown in from the beach.

The accumulation of sediments in the estuary mouth should not be a major problem. When the mouth opens naturally, there should be a large enough head of water to scour out the channels in the flood tidal delta and the water passing out of the estuary should be flowing fast enough to carry a great deal of the sediment with it. However, if the water level in the lagoon is not high enough and the mouth is opened prematurely, the scouring effect will not be sufficient to remove the sediment (Day, 1981). When the mouth first opens, there is an outrush of water but as the level of the lagoon falls, the water flow slows and gradually, sea water penetrates into the lagoon at high tides, bringing in sediment which eventually blocks the mouth as the water flow out of the lagoon decreases as a result of a decrease in river flow and an increase in evaporation.

Table 3 shows water levels before and during periods in which the mouth is opened. It also shows the time taken to drop approximately 500mm. The data are for every opening since 1980.

Table 3 Water levels before and during periods when the estuary mouth is open

Date	Level before opening (m)	Level when mouth open (m)	Difference in levels (cm)	Time taken Hrs:Mins
9/09/84	3.825	3.358	47.2	5:35
25/07/81	3.423	2.894	52.9	4:06
1/07/83	3.420	2.951	46.9	4:18
5/09/82	3.205	2.594	61.1	7:30
18/11/80	3.180	2.734	44.6	24:45
7/12/81	3.024	2.506	51.8	13:36
14/01/84	2.322	2.266	5.6	7 days

Table 3 shows that in most cases the higher the water level before opening, the quicker the level falls by approximately 50cm, so the higher the head of water before opening, the stronger the initial outrush of water.

In the Bot River Estuary, the sealed mouth, a topographic low, acts as a washover channel (van Heerden, 1985) and marine sand continues to enter the estuary after the mouth has closed. This process is likely to occur in the Klein River Estuary as well, thus building up the barrier, as well as introducing more sediment into the estuary.

The mechanism for the closing of the mouth is a combination of factors, the decrease in water level and the increase in the height of the sand berm as well as introduction of marine sands and washover deposits. Water level decrease is caused initially by the outflow of water when the mouth opens. Evaporation, low riverine input and low runoff also play a part in decreasing lagoon levels. The barrier is built up by aeolian transport, washover and longshore drift.

In conclusion, it is clear that the accumulation of sediments at the estuary mouth is a problem in the Klein River Estuary. The main reason for this being premature mouth openings. If the water levels were allowed to reach a higher level, more sediment would be washed out of the lagoon when the mouth opened, and there would be little, if any build up of sediments in the lower reaches of the estuary.

The position of the estuary mouth should be left to develop naturally and if the mining of barrier sand is to continue, then this should take place at the highest area of the sand berm in order to allow a natural breaching at either the eastern or western sides of the sand berm.

CHAPTER 6

6. DISCUSSION AND CONCLUSION

The Klein River Estuary is a popular holiday resort, being an ideal place for all types of water sport. The area used to be renowned for its excellent fishing but according to local fishermen, the fish catches have been decreasing over the last few years. One of the reasons for this is thought to be the accumulation of sediment in the estuary mouth, which is caused by the premature opening of the estuary (Heydorn and Tinley, 1980).

The estuary is bordered by sandstones of the Table Mountain Group to the north, and calcified dunes and aeolianites to the south. The soil is shallow and relatively infertile, and the land is used mainly for grazing. The land between the lagoon and Stanford is more fertile and is used for growing cash crops such as onions and potatoes.

The Klein River is the only substantial river flowing into the lagoon, but, particularly during the winter, small streams on the northern banks also carry runoff from the Kleinriviersberg. The vegetation on these mountains is mesic mountain fynbos with a high degree of species richness. The southern banks of the estuary are vegetated by south coast strandveld and various types of alien vegetation - mainly Australian acacias.

The Klein River carries very little silt except during high floods and the water tends to be brown (peat-stained), but clear. The river flow peaks in June, July and August, which are periods of high rainfall. The rate of runoff into the river and estuary is fairly low, as is soil erosion in the area.

The river itself has large stands of alien vegetation growing in the water and on the banks, for almost its entire length. This vegetation causes problems such as abnormally high flood levels, slower river flow, inducing siltation and blocking the river with debris. The stands of vegetation

are mature and would be expensive to remove.

The Klein River Estuary supports a normal flora and fauna and is a healthy system. Chapter Five highlights the main aspects of the Klein River Estuary that are affected by high water levels. The most important of these aspects is the problem of sediment accumulation in the mouth of the estuary which occurs as the result of premature breaching. Any management policy formulated for this estuary should concentrate on this problem and how to solve or minimise it. The simplest solution is to allow water levels to rise as high as possible, and thus to allow the estuary to breach the mouth naturally. This would ensure maximum possible flushing of the mouth area and would result in a net decrease in sediments in the lower reaches of the estuary. Unfortunately, high water levels can cause other problems, the major one being the flooding of property on the shores of the estuary and along the Klein River. Structures have been built on the shores of the lagoon that are susceptible to flooding and that in the past, have forced the mouth to be opened prematurely. The areas flooded are some of the lower campsite at the 'Die Mond' caravan park, some buildings in Maanskynbaai, the Yacht Club jetties, a short stretch of road near Springfontein and some fields on the southern banks of the Klein River. Some property in Stanford is also flooded but this could be a combination between high estuary water levels and extensive alien vegetation growing in the river. This vegetation is so dense that it causes abnormally high fluvial water levels. None of the above problems is very serious. High water levels usually occur in winter so the loss of some of the lower campsites at the caravan park would not be inconvenient since there are few visitors at this time of the year.

Owners of property in Maanskynbaai have permission to build semi-permanent wooden structures only (I Visagie, pers. comm.). Any brick houses or permanent buildings in this area should not have been built since the area is susceptible to flooding. Planners must enforce these regulations to prevent structures from being built in such areas. If

houses are flooded by high water levels this puts constraints on the management of the estuary.

The Yacht Club jetties can be covered by about 20cm of water during periods of high water levels. The jetties are not actually used for mooring, but provide shelter when the wind is strong. If they were submerged during the winter, they could prove to be dangerous. It is recommended that marker posts are attached to the jetties at regular intervals to prevent any collisions when they are covered by water.

About 40m of the road to the 'Le Bos' Forestry Station would be flooded (Fig. 15). This occurs in the area where the river enters the lagoon, near Springfontein farm. The road actually runs below the 5m contour. It would be possible to divert this road to the south of the farm, thus taking it along a ridge above the 5m contour and avoiding flooding. The high water mark is just below the 5m contour and it is in this area that some fields are flooded during periods of high rainfall.

The developments on the Klein River affected by high water levels are mainly proposed developments in Stanford. There are also a few houses that have already been built on low lying land that are in danger of flooding during high river levels (van Rooyen, pers. comm.). The areas most susceptible to flooding are shown in Fig. 16 and if any new houses are built in this area, there is a very real danger of them being flooded. If developments are to take place in this area, it is recommended that any houses that are likely to be flooded be built on supports or piles to prevent damage from flooding. The best option is to prevent development on areas liable to be flooded.

Property along the Klein River is mainly farmland, on which cash crops such as potatoes, onions and marrows are grown. There is the possibility of this land being flooded when water levels are high (Fig. 15). It is clear from this figure that the fields flooded are below the 5m contour and are on the floodplain of the river. Strictly speaking these fields should not be cultivated, and if they are, owners

must accept that they will be flooded from time to time.

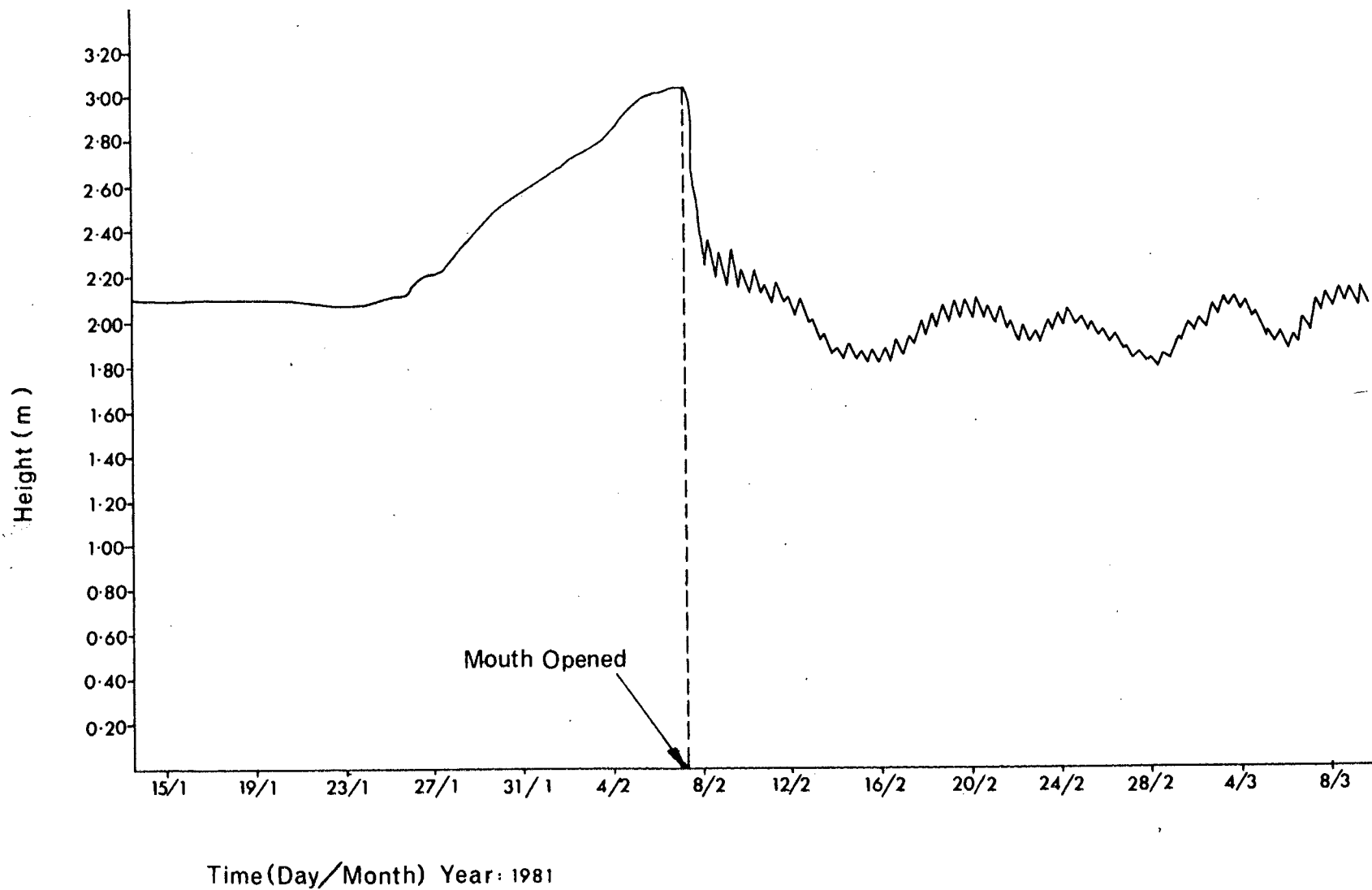
Some property upstream from Stanford may be flooded but this could be alleviated by removal of the alien vegetation. Opening the estuary mouth prematurely would prevent immediate flooding, but the real cause of this flooding is the growth of alien vegetation in the river (Van Rooyen, pers. comm.).

The quality of recreation on the estuary benefits from high water levels. The area of the lagoon at the highest level is 11.28 km^2 , twice that of the middle level, (area 5.6 km^2). This means that there is much more space for recreational activities. Although the lagoon has been divided into sections for recreational activities (Fig. 17), these divisions will be changed in the near future making the lagoon available for all sports in all areas. If this is the case, boat speeds in the channels at the estuary mouth should be controlled. Fast boats have large wakes which disturb stationary fishing boats and which can also cause bank erosion. This would apply especially at low water levels. Another advantage of high water levels is that the estuary is more accessible for the launching of boats. Much of the property around the estuary is privately owned and there are few public launching sites. These are reduced to only two during low water levels - at 'Die Mond' and at the Yacht Club. This can be very inconvenient since the area is so popular for water sports.

The estuarine biota is adapted to changes in the environment, but the changes brought about by a closed estuary suddenly being opened to the sea can be quite drastic. There is a rapid drop in water level, changes in the salinity, temperature and water currents, and tidal influence. Some of these changes can be seen in Fig. 25 which shows the rise and fall in water level and the tidal effects on the lagoon when the estuary mouth was opened in February 1981.

If the estuary is allowed to reach a high level before opening, the effects of the mouth opening are dramatic.

Fig. 25 Digitised recorder graph showing tidal effects on the lagoon after the mouth has been opened.



There can be a complete change in fauna under these circumstances as a result of the extreme salinity changes (Day, 1950). The estuary will have a low salinity just before the mouth opens, due to the high fluvial input which causes the water level to rise. When the mouth opens, the salinity will increase rapidly, bringing about a change in the fauna (Scott et al., 1950). Some marine species (eg *Callinassa kraussii*) can survive at low salinities, but cannot actually breed (Forbes, 1978), so although a population is present, it does not reproduce until the estuary opens, and the salinity increases. If the estuary were to be opened at lower water levels, the change in salinity would not be so rapid nor so great and the species change would not be as extensive. It must be borne in mind that the most natural situation in a semi-closed estuary is one in which violent fluctuations in water level can occur. Calculations show (Appendix 2) that the highest level has the longest shoreline so would have the highest potential for littoral communities and the highest potential for the formation of a species rich zone between the water and the land.

When the mouth is opened, large expanses of *Ruppia* and *Zostera* beds are exposed, especially if the water level has been high before breaching of the sand berm. The fauna in these reed beds either die through sudden exposure or are more easily exploited by fishermen for bait. These populations normally recover rapidly once the water level rises again, although there are records of collapse of *Ruppia maritima* with slow regeneration in the Bot River Estuary when the mouth was opened (Branch et al., 1985). The physiological condition of fish trapped in an estuary improves due to the decrease in predation, increased food availability and the fact that the fish do not spawn in the estuary (De Decker & Bennet, 1985). From this point of view, it is beneficial to leave the estuary closed as long as possible, which would mean that the water level should be allowed to rise as high as possible.

On the other hand, species important to sport fishermen are all marine migrants (Bennet, 1985) thus breaching of the

sand berm is essential if these species are to be available to fishermen. Some species, such as *Lithognathus lithognathus* (white steenbras), *Mugil cephalus* (flathead mullet), and *Rhabdosargus globiceps* (White stumpnose) are dependent on estuaries as nurseries (Wallace et al., 1985). It is advantageous to these species, therefore, for the estuary to be open at a time which coincides with spawning. Most fish have an extended spawning season but peak activity is usually between August and November (Bennet, 1985). Fig. 21 shows average monthly water levels between August 1979 and February 1985. It can be seen from this that in most years the water levels increase between August and November and the estuary is in fact open for at least one month between August and November. If the Klein River Estuary is to be opened artificially, to maintain a healthy fish population, it should be opened during this period. It also should not be opened too frequently since fish benefit from being trapped in an estuary.

Conclusions

The conclusion of this study is that the estuary water levels should be allowed to rise as high as possible to ensure a natural breaching of the sand berm. Problems can arise because some properties on the banks of the estuary will be flooded. The most serious flooding occurs in Maanskynbaai where planners have allowed structures to be built below the flood line. This area is susceptible to flooding and only semi-permanent wooden structures are allowed.

It is recommended that landowners should not be allowed to build brick houses or permanent boathouses in this area. If permitted these would be flooded and there would be pressure for a premature, artificial breaching of the sand berm at the estuary mouth. This would restrict the proposed natural management of the Klein River Estuary.

The fields that are flooded all lie below the high water mark or are on the floodplain of the Klein River and should not be ploughed or cultivated. If land is cultivated so

close to a river or estuary, a buffer strip of natural vegetation should be present along the bank between the water and the cultivated land (Clark et al., 1980). This protects the edge zone and helps prevent soil erosion. The Conservation of Agricultural Resources Act No. 43 of 1983 provides for such a buffer zone but the law is rarely, if ever, enforced.

Developments in Stanford are also threatened by high estuary water levels. Future developments should not be allowed in low lying areas but some houses have already been built too close to the river and have already suffered from flooding. It must be stressed that the areas shown in Fig. 16 have been flooded in the past and are likely to flood again so they should not be built upon.

A major problem with this estuary is the accumulation of sediment near the mouth of the estuary. The higher the water level rises, the more sediment is likely to be removed when the mouth opens. This should be a prime consideration in the management of the Klein River Estuary. The location of a breaching site should not be decided upon until the extensive SANCOR/NRIO Walker Bay Study results are available. Until then, the estuary should be allowed to breach naturally. Since this is a popular place for fishing, it should be remembered that the best months for fish spawning are between August and November. It is advantageous, therefore, for the estuary to be open during this time since young fish will then be recruited into the estuary.

This thesis has not stated a maximum level to which water in the estuary can rise. It has shown that the highest levels that have been achieved within the past six years are acceptable and that the problems caused by such levels are not as serious as was thought.

Within the next few years, a maximum height will have to be decided. Until then, it is recommended that the water levels be allowed to rise so the sand berm is breached naturally. This would achieve maximum sediment flushing and

maximum interchange of fauna and water with the sea.

Low-lying developments should be prevented and if possible, removed. If such developments are permitted they must be of such a nature that they are not damaged by flooding and so will not necessitate premature opening of the estuary mouth. In the case of the Klein River Estuary the hypothesis, that the best form of management for a natural system is that which involves no (or minimal) human interference, is supported.

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South Africa, 1:10 000. Orthophoto Map, Sheet 3419 AD20 Stanford, 1st Edition. Pretoria Government Printer. 1977.

Aerial Photographs

<u>Date</u>	<u>Job</u>	<u>Scale</u>	<u>Type</u>	<u>Source</u>
1937	130/38	1:25 000	B/W	Dir. Surveys, Mowbray.
1950-55	208	1:15 000	B/W	Dir. Surveys, Mowbray.
1961	461	1:36 000	B/W	Dir. Surveys, Mowbray.
1973	719	1:45 000	B/W	Dir. Surveys, Mowbray.
1977	282	1:45 000	Colour	Univ. Natal.
1979	332/3	1:10 000	Colour	Univ. Natal.
1980	347	1:25 000	B/W	Univ. Natal.
1981	391	1:35 000	Colour	Univ. Natal.

I would like to acknowledge the following for their help:

Dr R Bally	Department of Zoology, UCT.
Mr B Bennett	Department of Zoology, UCT.
Dr D Coetzee	CDNEC, Jonkershoek.
Mr J Conradie	Stanford Resident.
Dr J Neethling	Director, CDNEC.
Mr C Sim	Town Clerk, Hermanus.
Dr H Swart	NRIO, Stellenbosch.
Dr I Van Heerden	NRIO, Stellenbosch.
Mr I Van der Merwe	Directorate of Forestry.

APPENDIX 1

The data collected by Mr G E Franks on the Klein River estuary.

The data is concerned with the position of the mouth when the estuary is open to the sea. It has been collected from 1948 - 1984 and includes some remarks by Mr Franks, who was a keen angler.

OPENING OF THE HERMANUS (KLEINRIVIER) LAGOON.

1948: On the East side: This was the year when a family was washed out to sea and two people drowned.

1949: On the East side:

1950: On the East side: This was the year when the writer started fishing on the lagoon; at that time the out-flow was tremendous at spring tides and the in-flow so great two anchors were needed to hold a small boat and the fishing was excellent.

1951: On the East side: The above remarks apply. One could see large steenbras standing on their heads feeding in shallow water as the tides came in (Kopstanders).

1952: On the West side: There was then a fairly deep channel leading to the sea on this side and the flow was almost as good as the East side openings and the fishing good but this channel has long since silted up due to Middle openings.

1953: On the West side: The above remarks apply.

1954: On the West side: The above remarks apply.

1955: On the East side: Again excellent out and in-flow and good fishing, etc.

1956: On the East side: Ditto. N.B. This opening remained open untill March of the following year and the flow was so good that galjoen came in with the tide and were caught in large numbers.

1957: In the Middle: This was the start of the "bad openings" and the eventual silting up of the West side channel and damage to the lagoon. Only the surface water could run off and the lagoon could not drain efficiently neither could large fish get in or out. The Middle opening was deliberately done with the object of obtaining the earliest possible closing of the mouth so that Jeeps etc. could be driven across. One man is believed to be responsible for this.

1957-1962: In the Middle: This series of Middle openings brought about a rapid fall off in the flow of water and scouring effect, an accumulation of weeds, and an almost complete lack of worth catching fish. This went on for five consecutive years untill the angling public rose in protest and formed an association and pressure was brought to bear to have the lagoon properly opened.

An association was hurriedly formed and a deputation approached Mr. Milton the Forestry Officer, and asked him if he wouldn't open

the lagoon either on the East or West side. This he refused to do. The Association then called a meeting and, after much discussion, approached the Government and various bodies concerned with Conservation, inland waters ,etc. etc., and a large meeting was held in situ and it was decided that the lagoon should be opened for five consecutive years on the East side and the matter brought up for review after that period; unfortunately, as it turned out, this was construed by the protagonists of the West side, that this automatically meant that it would be opened there at the expiry of the five years and this was done and proved disastrous.

1963: On the East side: The result of this opening exceeded all expectations and the flow was wonderful and the fishing spectacular.

1964: On the East side: This was again a good year as were the following three.

1965: On the East side:

1966: On the East side:

1967: On the East side: This was the last of the good years for some time and the flow and fishing excellent and lasting well into April 1968.

1968: On the West side: Having decided that "the East had its turn" it was opened on the West side in spite of warnings that it would not flow and the net result was that only surface water drained off and no big fish could get in and there was practically no scouring effect to remove weeds and rubbish. Only one large fish was caught and the majority were undersize to minute.

1969: On the west side: On the principle that "it will take time to develop" it was opened again on the west side with very much the same result, although an artificial channel had been pre-dug before the lagoon filled, and the mouth remained open for four weeks, as against one the previous season !!

1970: On the East side: Pressure having been brought to bear, the lagoon was once more opened on the East side with again spectacular results as to flow and fishing and most people with any real knowledge of the lagoon were satisfied.

1971: On the East side: This was again a very good opening with similar results to the previous year.

1972: In the Middle: After a great deal of controversy about the east or west side opening and on the excuse that "no one could make up their minds" it was opened in the Middle once more with the result that enormous damage was done and the West side was finally silted up for good. Only surface water was able to escape and no fish of any size were able to enter with the result that

people were catching numerous undersized fish.

1973: No opening: For the first time in living memory the winter rains were so poor that the lagoon never filled up and could not be opened so the position remained static.

1974: In the Middle: It had been hoped that a lesson had been learned from the 1972 opening but, in spite of this, it was again opened in the Middle and further damage, silting and weeding up took place and no large fish could get in neither could they get out.

There the position remains and the power still seems to be in the hands of the one man who has the "say" and, in the writers opinion, unless something is done soon the lagoon will be ruined for good.

1975: In the Middle: Comments more or less in line with the 1974 openings.
Opened 26.9.75 - closed 6.10.75.

1976: In the Middle: Ditto. Opened 21.6.76 - closed 31.12.76.

1977: In the Middle: Ditto. Opened 28.6.77 - closed 10.10.77.

It is believed that this coming opening is of vital importance if the lagoon is to be saved and the weeds washed away, but it is said that it will either be in the middle again, which will lead to the final ruination of the lagoon as a tourist attraction, or on the West side which cannot work owing to the complete silting up of the old channel. Apart from every aspect of the opening it is a great pity that every year the lagoon is opened long before it is properly full, with assistance of bulldozers etc., at the behest of the Stanford farmers whose lagoonside land becomes flooded, and the initial rush of water which would do much to clear the lagoon of weeds and rotting rubbish, is lost.

It is a great pity that the opening of the lagoon is undertaken by people who have little knowledge and less interest in it, or so it would appear.

1978: On the East side: Opened 5.9.78 - closed 15.1.79. Strong pressure was made by the anglers interested to open the lagoon this year as near to the sand dune in the East as possible. The Forest Officer, Mr. Fourie and Mr. Eksteen of the Divisional Council were in complete agreement with the above, and the lagoon was opened on September 5th 1978. The result was a great success. A large portion of the man-made dune was washed away and the channel moved more to the east. Angling was excellent, until netters got busy at night and the fish catchers tailed off. However, the lagoon remained open until 15th January 1979 leaving a large area of water and excellent yachting was experienced during the summer. The general feeling is that the lagoon should be left for nature to open but failing this the next opening should be

right next to the sand dune which will eventually lead to the opening being opposite the old and deep channel running in front of Winter Bay towards the Foresters' jetty and which will never silt up.

1979: On the East side: Opened 24.7.79 - closed 22.3.80. As in 1978 it was agreed by the Divisional Council (Rep.) and the Forestry Officer that the opening be made next to the artificial man-made sand dune and this operation was a complete success. Many "old timers" stated that it was years since such a rush of outgoing water had been seen, taking with it debris of all sorts which had accumulated in the lagoon.

Many meters of the artificial dune were washed away enabling the original eastern channel to have a more direct route to the sea and so bringing the opening back to the way nature had made it many many years ago. The fact that the mouth remained open for nearly eight months during which excellent angling was experienced, plus first class yachting in the lagoon, more than justified the eastern opening.

It is understood that that 1980 opening will be in the same position as 1979 which should guarantee another successful operation.

1980: On the East side: The lagoon remained closed for 7 months and on the 11th and 16th of March 1980 two unsuccessful attempts were made to open it but it appeared that it was not full enough for the volume of water to really get going on its outward rush and it closed on its own on 22nd March 1980. It remained closed until 18th November when another attempt was made to open it, this proved partially successful and it remained open until 12th January 1981 when it closed of its own accord through lack of sufficient rain.

1981: On the East side: Between 13th January and 7th February 192mm of rain fell and the lagoon became fuller than it has been for decades. The result was that "Papa Eksteen", the Divisional Council Representative and a couple of labourers were able to open the bar with spades on February 7th. This opening proved to be another "clean out" of the lagoon, and at the time of writing this record (June 14th) it is still open and running strongly from spring tide to spring tide. An excellent feature of this last opening is that the man made dune on the east side of the mouth has been scoured away by some 50 or more meters, it means that nature has taken a hand again removing a lot of this dune which has been blocking the main channel ever since the Forestry Dept. consolidated the sand dunes all along the plaat, too near to the sea, some 10-15 years ago. Angling has been good but mostly small to medium sized white steenbras plus elf and leervis of reasonable quantities. Unfortunately the local Conservation Officer resigned and plans are being made to replace him. In the meantime illegal trekkers are "having a ball" and greatly disturbing the fish life.

Just prior to the end of June 1981 very heavy seas were experienced caused by S.W. gales and vast quantities of sand was washed into the mouth of the lagoon with the result that a sand bar was formed and the mouth closed on June 27th. During the following spring tides a large volume of water poured over the sand bar and the level of the lagoon was raised quite a lot. Our rainy season is now upon us and the lagoon should fill rapidly. A new nature conservation Officer was appointed at the beginning of July 1981. 85mm of rain fell during the first 12 days of July and the lagoon is just about full.

1981: On the East side: owing to excellent rains during July, the divisional council opened the lagoon on the 25th July 1981, and made an excellent job indeed. Further inroads were made by the strong volume of water rushing out on the man made dunes (Forestry Department) and many more meters disappeared. The result is that the original deep channel running across the front of winter Bay has improved its outlet to the sea. This channel is now more in line with what it was some 50 years ago and is still running strongly between tidal movements. After nearly 9 months the lagoon mouth closed naturally on April 8th 1982. During this period the lagoon water was being refreshed every day with tidal sea water, and it remained clean and healthy right through the summer season. There was easy access to Die Mond by holiday makers and the general public. Angling was excellent and full scope was available for yachting.

August 23rd 1982. The lagoon was closed for 4 months and was over three quarters full. Another 50-60mm of rain would have made it ready for opening again. It is hoped by those who have studied the lagoon for many years, that an opening will be made on the Eastern side again to ensure a repeat of the successful openings during the last four years.

1982: On the West side: Alas, in spite of all the most satisfactory openings in the east in recent years, the Department of Nature and Environmental Conservation decided to open the mouth on the west side. This was carried out on Sept. 4th, 1982. The lagoon had been closed for four months and the latest opening only lasted for one month. A very weak outflow took place and compared to the easterly opening, much weed, bushes etc. were left in the lagoon. In the easterly openings all this rubbish was usually washed out to sea. Many years ago, successful openings were made from the middle and west sides, but since the sand dunes all along Die Plaat were stabilised too close to the sea some 15 years ago by the Forestry Department, the level of the sand over Die Mond is much higher than it was. This movement of sand from Die Plaat, caused by a westerly drift, has silted up most of the popular fishing spots by covering up the black mussels, worms, red bait etc., which most fish feed upon. The Forestry Department have agreed, through their representative, that when and as the sea erodes the consolidation, re-consolidation will only take place further in land out of reach of the sea. Dur-

ing the late 1930's there were no dunes next to the sea along Die Plaat and the beach was flat all along, past Soupie's Klip and beyond. The lagoon has now been closed for four months (Dec. 1982) but due to evaporation, lack of rain and mainly due to the fact that the lagoon is not tidal, the level has not been so low for many, many years. certain areas of the water are becoming stale and smelly and there is a general feeling that when the rains come the salinity of the water will be affected, causing fish to die, as in Lake Marina.

It has been observed that now the sand level is so high (near the sea) even spring tides and rough seas very rarely wash over into the lagoon, as in previous years. This means that very little water overflows from the sea into the lagoon.

On sept 4th 1982, it was decided to open the lagoon from the West (the last time it was opened in the West was in 1969). It remained open for one month and closed on 1st October 1982. It remained closed for eight months until July 1st 1983. the lagoon was very full then and partially with the assistance of a strong easterly wind, rough seas plus manual labour it was opened in the west again on 1st July 1983. It remained open for three months and closed again on 1st October 1983.

On 14th January it was decided to open the lagoon on the western side in order to freshen up the lagoon water. Thousands of Harders had died and most of them were washed out to sea. The lagoon was only approximately half full and there was not enough outgoing force to clean out the lagoon thoroughly. The outflow lasted one week and it is now closed again - 21st January 1984.

During the closed period it is hoped that the builders will be instructed to take their sand from the eastern side to lower the level, as time has proved that the most successful openings have been made from the east. Records show that eastern openings remain open up to nine months. By lowering the sand level on the eastern side, spring tides will be able to wash over into the lagoon and so keep the lagoon cleaner for a longer period.

With an eastern opening the whole Mond is available to the holiday makers and their vehicles.

Table of Mouth Openings in Hermanus Lagoon 1948 - 1984

Year	Position	Duration (Days)	Year	Position	Duration (Days)
1948	East	--	1968	West	--
1949	East	--	1969	West	--
1950	East	--	1970	East	--
1951	East	--	1971	East	--
1952	West	--	1972	Middle	--
1953	West	--	1973	--	--
1954	West	--	1974	Middle	--
1955	East	--	1975	Middle	10
1956	East	--	1976	Middle	162
1957	Middle	--	1977	Middle	122
1958	Middle	--	1978	East	130
1959	Middle	--	1979	East	241
1960	Middle	--	1980	East	6
1961	Middle	--	1980	East	55
1962	Middle	--	1981	East	140
1963	East	--	1981	East	298
1964	East	--	1982	West	30
1965	East	--	1983	West	92
1966	East	--	1984	West	7
1967	East	--			

Totals:

Eastern Openings - 19
 Middle Openings - 11
 Western Openings - 8

APPENDIX 2

The calculation of

Area

Volume

Shoreline length

Shoreline developments

for three different water levels.

APPENDIX 2

MORPHOLOGICAL PARAMETERS

The following morphological parameters were calculated for each level. The parameters have been calculated from the bathymetry of the lagoon and as the exact bathymetry is not known, an approximation has been used.

The main purpose for calculating these parameters is for comparison between the three water levels. Although the values obtained are not exact, they give a good idea of the morphological features of each water level. The results of these calculations are presented in Table 2. The results and effects of each parameter on three different water levels is discussed at the end of each section.

1. Height

1.1 Highest level

The Department of Water Affairs data set runs from August 1979 and gives the height of water levels in the estuary, throughout the subsequent years. Interviews with residents of this area suggested that the highest levels that most people could remember occurred within the last few years, hence it was decided to use the highest level recorded in the data.

The highest level is 3.8 m and was recorded on 9 September 1984. The mouth was closed at the time but opened on 10 September. The level fell from 3.8 m to 2.4 m in 14 hours 46 minutes and was low enough to be affected by tides (approximately 2,2m) after 36 hours.

The actual position of the highest water level could still be seen in April 1985, marked by debris high on the shore. The level of the water in April 1985 was 2.4 m and the position of the highest water level was determined using a theodolite. This position corresponded with debris on the shore and on some parts of the southern shore, the high

water level corresponded with a change in the vegetation and a small (wave-cut) step on the banks of the estuary. The vegetation change was from either salt marshes or mud and sand flats, to alien vegetation such as *Acacia longifolia* and *A. cyclops*.

1.2 Middle level

This level was chosen as a close approximation to sea level. When the estuary is open, it is affected by tides and the level fluctuates by approximately 80cm between low and high tides. The cycle of spring and neap tides can also be seen on the digitised recorder graphs, as presented in Fig. 25. This figure shows the levels in February 1981 and the tidal fluctuations can be seen.

1.3 Lowest level

The lowest level was chosen as the lowest recorded level in the data from the Department of Water Affairs. This level is 1.6m, recorded on 12th February, 1983. The mouth of the estuary was closed at the time, having opened last on the west side of the sand berm 4th September 1982 and closing again on 1st October 1982.

It is possible for the level of the lagoon water to decrease below the lowest level mentioned above, as can be seen in the 1973 aerial photo. Unfortunately, there are no records of the actual water levels during this year, and although one can tell from the bathymetry and the height of the water, it was decided to use a more practical lowest level, not an extreme case.

2 Area

The surface area of each contour and of three different water levels was calculated by the cut-and-weight method (Lind, 1979).

The surface area of each contour and each water level was traced onto good quality paper. The mass per square unit area of the paper was then determined by weighing square of

known area (10cm x 10cm, 5cm x 5cm and 1cm x 1cm). Each estuary surface area was then cut out, weighed and the area of each calculated as follows:

$$\text{Area of estuary at a particular level (cm}^2\text{)} = \frac{\text{Weight of cut out}}{\text{Weight of 1cm}^2}$$

This gives the area in square centimeters of each cut-out, which was then converted into the actual area in square kilometers.

The area at all three water levels was determined and this gives an idea of the area available at each level for recreation .

The area of the estuary at the three different levels varies considerably. The area of the highest is 11.28km² which is approximately 2.6 times larger than the lowest level (area 4.27km²) the area of the middle level is 5.6 km². The highest level includes a large area of shallow water in Winter Bay and in the upper reaches on the southern shore and west of Kettle Point on the northern shore. This water is all less than 0.5m in depth and covers sand and mud banks.

3 Volume

The volume of the lagoon at each water level and at each contour was established by calculation. If the estuary basin is considered as being a cone, the volume can be calculated using the equation:

$$\text{Volume} = 1.047r^2h$$

where h = height of the cone
r = radius of the cone

Since the slope of the estuary basin is not regular, a better approximation of the volume can be obtained by calculating the volume of separate conical segments (frustra) with the upper and lower surface of each segment delimited by the areas of sequential depth contours. The volume of the entire estuary is calculated by summing the volumes of each frustrum (Lind, 1979).

The following equation was used to calculate the volume of each frustrum:

$$V_1 = \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

where V_1 = volume of the frustrum

h = height between contours

A_1 = area of upper contour

A_2 = area of lower contour

The volume of the estuary for each level was calculated because it is an important parameter with respect to the flushing of sediments from the estuary mouth.

The volume of the highest level at $17 \times 10^6 \text{ m}^3$, is 2.8 times greater than the volume of the middle level at $8.87 \times 10^6 \text{ m}^3$, and 11 times greater than that of the lower level ($4.08 \times 10^6 \text{ m}^3$). The volume measurements become important when considering the sediment transport out of the estuary when the mouth is open. It is assumed that the larger the volume of water, the more sediment will be scoured from the estuary when the mouth opens. It is important that sediments are removed from the estuary mouth as the accumulation of sediment is thought to be a problem in this estuary.

The area and volume were also calculated using a computer programme called 'x Area' and 'Estvol' (Reddering, 1985). Seven transects across the estuary were used in the programme to calculate the surface area and volume of the estuary at the three levels. Unfortunately, there were insufficient data available to make the results of this method as accurate as the other methods (more data were used to plot the bathymetry, but the points were random, not in transects). However, for the purposes of comparison it was considered that the exercise was worthwhile. The results from the computer programme are presented in Appendix 3.

4 Shoreline length

The shoreline length was calculated by using a opisometer, which gave the length in centimeters. An orthophoto map at

a scale of 1:10,000 was used permitting simple conversion, to actual length in kilometers.

The shoreline length at the highest water level is 26,83km, 1,5 times longer than the lowest level, which is 17,46km the shoreline length at the middle level is 18,38km. This suggests that there is a greater opportunity for the development of littoral communities when the water level is high, because there is more shoreline. The transitional zone between land and water is important in terms of providing protection for birds, juvenile marine or estuarine organisms and for the production of detritus and nutrients in the estuary (Heydorn and Tinley, 1980). An estuary will thus benefit from a longer shoreline.

5 Maximum depth

The maximum depth is the greatest depth of the lagoon and when gathering data for bathymetrical calculations, the maximum depth was found to be 3.5m in the middle of the channel west of Pulpit Point. This depth was measured when the hydrological station at the Yacht Club indicated the water level to be 2.7m so it is assumed that the maximum depth of any one level measured by this station is the given level plus 0.8m. Unfortunately, it is not known exactly at what height above sea level the hydrological station is situated, since this station has yet to be surveyed.

6 Filling time

The time it takes to fill the estuary was calculated to give some idea of the time it would take for the water level to rise, given a certain input.

The calculation used for determining filling time is the same as that for calculating Residence time:

$$\text{Filling time} = \frac{\text{Volume}}{\text{input or output}}$$

The results are expressed in the number of days it takes the estuary to fill.

There are three main sources of input into the Klein River Estuary:

- Rainfall
- The Klein River
- Runoff from the Kleinriviersberg

The output has two main components:

- Flow through the mouth (when open)
- Evaporation

Information from the hydrological station on the Klein River was used to calculate the input into the estuary. The data running for the hydrological year 1975/1976 gives the total seasonal flow in millions of cubic meters. The presence of this hydrological station makes the input into the estuary easy to measure.

The total seasonal flow from 1975/1976 to 1984/1985 was $265.77 \times 10^6 \text{ m}^3$ for these nine seasons. The average seasonal flow was $2.953 \times 10^7 \text{ m}^3$ per year. This figure is a conservative estimate since in some years, the direct runoff from the Kleinriviersberg into the lagoon can be quite high.

The input into the estuary was then used to determine the filling times for the three different water levels.

The water would take 301.7 days to reach the highest level, if the estuary was completely empty, but only 50.4 days to reach the lowest level. It can be seen that the water level would rise rapidly at first (328mm a day) then the filling rate slows until it only rises at a rate of 126mm a day.

These calculations were done assuming the average rate of fill is 2.953×10^7 cubic meters per annum. This rate can change as mentioned previously. The rate of fill is likely to be faster in the winter and slower in the summer when there is less rainfall.

7 Maximum length

The maximum length is the straight line distance between the two most distant points on the shore, uninterrupted by land.

In the case of this estuary, lies in an east-west direction. This is the maximum fetch uninterrupted by land and so the longer it is, the more effect prevailing winds will have on the estuary.

The maximum open water length for the highest water level is 7.45km, and for the lowest level, 5.20km. This is large enough to provide enough fetch to ensure wind mixing in the estuary at all water levels.

8 Maximum breadth

This is the maximum distance uninterrupted by land, at right angles to the line of maximum length. This parameter does not have any special significance, but is important in describing the morphology of the estuary.

The maximum breadth for each level is fairly similar, the highest level being 2.00km, the middle 1.85km and the lowest 1.75km.

Table 2. Morphological parameters of the Klein River Estuary.

PARAMETERS	WATER LEVEL		
	Highest	Middle	Lowest
Height (m)	3.825	2.186	1.658
Area (km ²)	11.28	5.60	4.27
Volume (m ³)	24,41 × 10 ⁶	8.87 × 10 ⁶	4.08 × 10 ⁶
Shoreline length (km)	26.83	18.38	17.46
Maximum Depth (m)	4.625	2.986	2.485
Filling Time (days)	301.7	109.63	50.4
Maximum Open Water length (km)	7.45	6.60	5.20
Maximum Open Water Breadth (km)	2.00	1.85	1.75

APPENDIX 3

The calculation of surface area and volume of the Klein River Estuary by computer programme.

'X-Area' (Reddering, 1985) is a BASIC programme and calculates the cross sectional area of transects across the estuary. It also calculates hydraulic radius and width of channel at different water levels. This information is then used to calculate the surface area of the lagoon at different levels.

ESTVOL (Reddering, 1985) calculates the volume of water between each cross section. It then sums these to give the volume of water in the estuary at different levels.

The more extensively the estuary is surveyed, the better the results obtained from these two programmes. Unfortunately, only seven transects were made, which did not really provide sufficient detail. These parameters have been calculated using other methods because the random bathymetrical data gathered could then be used, the results are presented in Appendix 2..

Table 1 shows the results from 'X-Area', with the transects going from the mouth to the upper reaches of the estuary.

TABLE 1.
CROSS SECTION INFORMATION FOR THE KLEIN RIVER ESTUARY.

Cross section data for line A

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	8683.5	4.02	2160.0
1.50	2471.0	1.78	1390.0
1.00	1803.5	1.41	1280.0
0.50	1191.0	1.02	1170.0
0.00	633.5	0.60	1060.0
-0.50	254.2	0.46	552.8
-1.00	32.0	0.10	320.0

Cross section data for line B

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	7663.5	4.33	1770.0
1.50	2571.0	2.26	1140.0
1.00	2023.5	1.93	1050.0
0.50	1420.4	1.58	962.5
0.00	1063.6	1.25	849.5
-0.50	685.7	1.00	685.5
-1.00	372.1	0.65	568.9

Cross section data for line C

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	9703.0	5.81	1970.0
1.50	4103.0	2.68	1530.0
1.00	3343.0	2.21	1510.0
0.50	2594.5	1.78	1460.0
0.00	1907.0	1.48	1290.0
-0.50	1415.2	1.61	877.7
-1.00	989.1	1.2	826.6

Cross section data for line D

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	14128.8	6.86	2060.0
1.50	7065.8	3.58	1976.0
1.00	6080.8	3.10	1964.0
0.50	5101.8	2.61	1952.0
0.00	4128.8	2.13	1940.0
-0.50	3173.8	1.69	1880.0
-1.00	2247.6	1.23	1831.8

TABLE 1 cont....

Cross section data for line E

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	10863.0	5.51	1970.0
1.50	4262.0	2.63	1802.0
1.00	3367.0	1.89	1778.0
0.50	2484.0	1.42	1754.0
0.00	1630.2	0.98	1661.3
-0.50	941.5	0.84	1120.0
-1.00	493.7	0.64	770.5

Cross section data for line F

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	4255.8	5.00	950.0
1.50	1538.0	2.19	703.0
1.00	1191.8	1.75	682.0
0.50	856.0	1.29	661.0
0.00	530.8	0.83	640.0
-0.50	301.1	1.14	264.5
-1.00	187.1	0.98	191.7

Cross section data for line G

ELEV. (m)	X-AREA (m ²)	HYDR R (m)	WIDTH (m)
5.00	4221.0	5.86	720.0
1.50	1811.3	2.76	657.0
1.00	1485.0	2.29	648.0
0.50	1163.3	1.82	639.0
0.00	846.0	1.34	630.0
-0.50	550.1	0.99	553.5
-1.00	295.0	0.63	467.0

Table 2 shows the difference in the results obtained by the computer programmes and the results obtained by hand calculations.

Water Level	Volume $m^3 \times 10^6$		Area km^2	
	EST VOL	Hand Calculations	X AREA	Hand Calculations
5m contour	71,4	31,05	13,9	14,49
Highest Level	24,3	24,41	11,4	11,28
Middle Level	13,9	8,87	10,4	5,60
Lowest Level	6,3	4,08	6,7	4,27

12 MAY 1987